1965

The effect of vegetation, soil, and rock type on runoff from some small watersheds in Missouri

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THE EFFECT OF VEGETATION, SOIL, AND ROCK TYPE ON RUNOFF FROM SOME SMALL WATERSHEDS IN MISSOURI

BY

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A

THESIS

submitted to the faculty of the

UNIVERSITY OF MISSOURI AT ROLLA

in partial fulfillment of the requirements for the

Degree of

MASTER OF SCIENCE IN GEOLOGICAL ENGINEERING

Rolla, Missouri

1965

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ABSTRACT

A previous study of mean annual floods (Harbaugh, 1962) was based on watershed area, channel length, and channel slope of forty five small watersheds in the State of Missouri. The present study investigates the effect of precipitation, soil distribution, vegetal cover, and underlying bedrock on annual peak rate of discharge. This study consists of statistical analysis by multiple correlations of additional quantitative data for nine of Harbaugh's forty five watersheds.

Hydrologic data were obtained from the U. S. Geological Survey and U. S. Weather Bureau climatological publications. Distribution of vegetation was compiled from U. S. Department of Agriculture aerial photographs. Soil and rock type data were compiled from available references, reports, and maps. Statistical analysis of data was computed on an IBM 1620 computer at the UMR Computer Center.

Statistical analysis revealed that of the variables tested, twenty-four-hour antecedent precipitation has the greatest effect on runoff. The highest multiple correlation coefficient found, 0.42, was for the equation

$$Q = 111 + 62\,X_1 - 1.6\,X_2 + 0.4\,X_3$$

where Q is the peak discharge in cfs/sq. mile, X_1 is twenty-four-hour antecedent precipitation in inches, X_2 is percent forest cover, and X_3 is percent of gravelly and stony loam present. Although the wide range in some data, and unforeseen intercorrelations of independent variables, caused errors in statistical computation, the regression

equations can be used as indication of which variables may be most significant in estimating momentary peak discharge.

Simple correlation and regression analysis between percent forest cover and the difference between mean annual flows obtained from frequency curves in this study and mean annual flows estimated by Harbaugh's equations showed that Harbaugh's equations were designed for watersheds of 77 % average forest cover. The coefficients of determination and simple correlation of this flow difference versus percent forest were found to be 0.22 and -0.465 respectively. From the regression equation it was apparent that Harbaugh's equations would be improved by adding "+54 - 0.7 (percent forest)" to each equation.

ACKNOWLEDGMENTS

The author expresses his sincere appreciation to Dr. James C. Maxwell, Associate Professor of Geology, University of Missouri at Rolla, for his advice and guidance during the course of this study. Thanks are due to Mr. William K. Winters, Assistant Professor of Computer Science, University of Missouri at Rolla, for his helpful assistance in statistical and computer application. Thanks are offered to the U. S. Geological Survey and the Missouri Geological Survey and Water Resources, the U. S. Forest Service, and the U. S. Department of Agriculture, for allowing the use of data files. Special recognition is due the author's wife, Chirapa. Her help and constant encouragement has made this paper possible.

TABLE OF CONTENTS

LIST OF TABLES

I

INTRODUCTION

A. RUNOFF AND WATERSHED CHARACTERISTICS

In engineering design of flood control and other hydraulic structures, the volume of streamflow at peak discharge is the basic problem to study. Stream and rainfall gaging records are the primary data for watershed hydrologic analysis. It is evident that watershed characteristics, as well as rainfall characteristics, affect the surface runoff of the drainage basin. Watershed characteristics governing the amount and rate of runoff are: sise and shape of drainage area; channel length and slope; physical nature of the soil; distribution and kind of vegetal cover; and geology of the drainage area.

The area and topography of the land has a great deal to do with the amount of surface runoff, because it determines to a large extent the length of time required for water to concentrate or collect at a given point. On very hilly land having steep slopes, the runoff is much greater than on flat lands. Large areas will give a greater amount of discharge but generally a smaller rate of runoff than small areas, because they receive more rainfall which requires a longer time of concentration.

The physical characteristics of the soil determine its hydrologic infiltration and percolation rates. When infiltration and percolation rates and soil storage capacity are high, immediate surface runoff for a given storm will be low. Conversely, at the opposite extreme of low infiltration rates with little storage, a much larger part of the precipitation will occur as surface runoff, with a consequent marked increase in peak rate of stream flow.

Vegetation affects the amount of runoff by the interception of rain. Interception storage capacity is usually satisfied early in a storm so that a large percentage of the rain during the first part of a storm and in numerous small storms is intercepted. Vegetal cover does increase infiltration because it retards surface flow; the root systems make the soil more pervious, and the foliage reduces rain packing of the surface soil. The vegetation also decreases the runoff by removing soil water by transpiration.

For basins having permeable surface soils, precipitation which infiltrates will percolate downward until it reaches the water table. This groundwater accretion may eventually discharge into the streams as groundwater flow, also called base flow. The proportion of the total runoff which occurs as base flow is dependent on the geology of the basin. The interstices of rock, which act as groundwater conduits, vary through a wide range of sizes and shapes. Generally, they are very small and interconnected, permitting movement of the groundwater, but in some rock they are isolated, preventing the transmission of water between interstices. Accordingly, the permeability in the rock of a given area is largely determined by the geology of that area.

B. OBJECTIVES

Hydrologists realize that watershed area alone is insufficient to explain the wide variation in peak rates of runoff existing among watersheds. It has been discovered that if one or more of the watershed characteristics mentioned above are added to the watershed area factor as independent variables, the prediction of the magnitude of the peak rates of runoff can be improved.

Harbaugh (1962) studied the relation of mean annual flood to topographic characteristics: area, length, and slope, for 45 small watersheds within the State of Missouri. The objectives of this study are to determine the effect of precipitation, vegetal cover, soil, and rock type on runoff, and to develop a procedure for predicting peak discharge from hydrologic, vegetal, soil, and rock type data. The relationship between these variables was determined by statistical analysis using an electronic digital computer. A sample of nine watersheds for this study were selected from those used in Harbaugh's study.

C. DESCRIPTION OF THE AREA

Branson (1944) classified the topography of Missouri into four divisions: Ozark Region, Western Plains, Glaciated Plains, and Southeast Lowlands (Figure 1).

The Ozark Region

The area of the Ozarks as defined by the Missouri Geological Survey covers a great part of Missouri south of the Missouri River, and part of a larger region extending into Arkansas and Oklahoma. The topographic character varies greatly within the region. Thickly forested hills, deeply entrenched and meandering streams, and many caves, sinkholes and large springs are distinguishing features of the Ozark region. Vertical bluffs of heighth of one hundred feet or more are common. The tops of the ridges are, in most areas, flat and narrow, but considerable upland areas are gently rolling.

The bedrock of the Ozarks is usually dolomite. Sandstone layers, of rather common occurrence, and solution channels in the dolomite are the aquifers feeding many springs and wells in the Ozarks. The cherty residual soils predominant throughout the area come from the dolomite. The sandstones decompose to modify residual soils or to form soils of sandy character. The top soil is often thoroughly leached of organic and clayey materials, and the subsoil may be a compact claypan as a result of the deposition of fine clay particles. Chert fragments usually accumulate on the slopes of many hills from which soil fines have been removed by surface drainage water.

The Western Plains

This region is the western part of Missouri south of the Missouri River and east from the Kansas line to the irregular boundary denoting the western limits of the Ozarks. Generally, the underlying rock formations dip toward the west. The surface rocks are primarily sedimentary cherty limestone and shale. Sinkholes and caverns are of rather common occurrence where the purer, more easily dissolved limestones occur.

Shales are the parent materials for large areas of southwest Missouri soils. The variety of soils which range from fine sand to clay is due in part to variations in parent materials, and in part to variety of topography.

The Glaciated Plains

The Glaciated Plains is the area north of the Missouri River. The southern boundary slightly overlaps the northern limit of the Ozark region.

This area was invaded by the Kansan and Nebraskan glaciers which are the two oldest ice sheets of the Pleistocene Epoch. The thick layer of drift deposited by these glaciers consists of a heterogeneous mixture of boulders, sand, and clay. This deposit has been rather completely weathered, resulting in clays with some boulders and gravels scattered at random throughout the matrix.

Much of the bedrock in the glaciated area lies deeply buried. Bedrock is mainly limestone and shale throughout the area. In general, the present topography of the Glaciated Plains is that of a gently undulating plain.

The soil-forming material of the northern half of the state is the glacial till which varies greatly in composition. The particle size range from the finest clay to boulders, indiscriminately deposited, with some concentrations of sand or gravel encountered at random. Also present is wind-blown soil, called loess, which consists of particles of silt size. The finer loess contains a great deal of clay and the coarser contains sand grains. Small quartz fragments make up a large part of the loess and the rest is largely composed of fragments of feldspar, mica, and hornblende.

The Southeast Lowlands

The Southeast Lowlands is a flat region located in the extreme southeastern corner of the state. It is part of the Mississippi River floodplain. The region was once largely swampland but drainage has converted the area into flat farming land.

Alluvial soils occur over the southeast lowlands. They range in texture from coarse gravel to the finest-grained clay, but in the main they are sandy loams.

D. CLIMATE

Missouri's average annual precipitation varies from 34 inches in the northwest to 50 inches in the southeast. One-half to two-thirds falls during the spring and summer months. Year to year departures of fifty percent or more from the average are characteristic.

The state's total seasonal snowfall from year to year ranges from 5 to nearly 40 inches and averages about 18 inches. Snowfall seldom plays an important part in the occurrence of floods in Missouri.

II

PREVIOUS WORK

Potter (1960) stated that watershed area alone is insufficient to explain the wide variations in the magnitude of peak rates of runoff. He plotted the relation of watershed area to peak streamflow of 10-year average recurrence interval for 96 gaged watersheds located east of the 105th meridian. The wide scatter of plotted points on the graph is the evidence supporting his statement. In estimating peak rates of runoff, Potter found two indices, in addition to area, to account for the wide variation in the magnitude of the 10-year peaks: a topographic index, T, and a precipitation index, P. The topographic index, T, was defined as the sum of the ratio of seven tenths of the length of the principal stream channel, measured from its lowest point, to the square root of its slope and the same ratio determined for the remaining three tenths of its length. Precipitation index, P, was defined as the amount of precipitation measured in inches of rainfall, that might be expected to be equalled or exceeded during a 60-minute period on an average of once in 10 years. Although the method was an improvement from the consideration of watershed area alone, the graphical correlations between 10-year peak, area, topographic index, and precipitation index still showed unexplained large differences between some of the estimated peaks and the corresponding values derived from stream measurement. It appeared that the differences was not more than ±20 percent of the estimate for 68 percent of the gaged watershed sample, but over 100 percent for 5 to 10 percent of the sample. It was found that the errors in these estimates of 10-year average recurrence interval bear a close relation to the corresponding errors in the estimated value of T. The errors in estimates of T, obtained from the correlation between T, P, and A, were explained by difference in the drainage characteristics as measured by the watershed's drainage density index, D. Drainage density, D, was defined as the ratio of the summation of the length of all stream channels within a watershed to the watershed area. From graphical correlation test between T, A, P, and D, it was concluded that within a zone of homogeneous lithology a high degree of correlation did exist between T and D.

Maxwell (1960) studied the relation between the observed morphological, geological, vegetative, and hydrologic data of mountainous watersheds of Southern California by statistical analysis using electronic digital computers. He computed five multiple correlations between annual peak discharge, cover density, and four different precipitation variables to obtain the estimated discharge. He found the 3-variable multiple correlation coefficient of maximum 60-minute precipitation during storm, cover density, and discharge, to be 0.556; for maximum 24-hour precipitation during storm, cover density, and discharge to be 0.786; so he considered that maximum 24-hour precipitation explained more of the variation in peak discharge. He found that the multiple correlation coefficient of 21-day precipitation prior to date of storm, maximum 24-hour precipitation during storm, and cover density on the watershed versus discharge was 0.807, from which he concluded that these three variables alone appear to account for nearly 65 percent of the variation in discharge. He also found an unexpected result in estimation equations for peak discharge: the estimating or regression coefficients of cover density were positive. The positive sign would indicate that the magnitude of flood peak discharge increases as the vegetal cover on a watershed increases, which is contrary to common experience. His explanation for this contradictory result is the incompleteness of the correlations, and that significant pertinent but unknown variables had been omitted.

Harbaugh (1962) studied the relation of watershed topographic characteristics (area, length, and slope), and the relation of mean annual flow to these characteristics for 45 small watersheds (0.26 to 8.36 sq. miles) located in different hydrologic areas in Missouri. He obtained drainage area, A; length, L; and slope, Sl; for each watershed from topographic maps published by the U. S. Geological Survey. From these data and their graphical correlation, the relation between L and A was found to be $L = 1.54\ A^{0.5}$ and between L and Sl was found to be $L = 0.255\ Sl^{-0.5}$. Harbaugh said these formulas are generally accurate for drainage areas of 1.5 to 10 sq. miles within the State of Missouri.

Harbaugh established curves used to estimate mean annual flood for drainage areas of up to 10.0 sq. miles in Missouri. The estimated mean annual flood formulas are given for three ranges of size as follows:
$MAF = 462(AL^2S^{1/8})^{0.30}$ for drainage area from 0 to 0.5 sq. mile;
$MAF = 210(AL^2S^{1/8})^{0.65}$ for drainage area from 0.5 to 1.5 sq. miles; and
$MAF = 113(AL^2S^{1/2})$ for drainage area from 1.5 to 10.0 sq. miles.
Harbaugh concluded that other factors should be investigated to seek an explanation of residual variation in mean annual discharge.

III

PROCEDURE OF THE STUDY

A. WATERSHED SAMPLES AND DATA COMPILATION

1. Selection of watersheds

Based upon data available, nine small watersheds were selected for the study. These watersheds were selected from forty five small watersheds in the State of Missouri which Harbaugh (1962) used for his study. Among the nine watersheds selected, the area of the smallest is 1.04 square miles, and the largest, 8.75 square miles. Five of them are located in the Glaciated Plains of northern Missouri, the others are scattered in the various parts of the Ozark Region of southern Missouri. Figure 1 shows the location of the watersheds.

The boundaries of the drainage areas were drawn along the watershed topographic divides as shown on 15- and $7\frac{1}{2}$-minute U. S. Geological Survey topographic maps. The basin areas were measured using a polar planimeter. Outlines of the watersheds are shown in Appendix II. The watershed names and measured areas are tabulated in Table 1.

2. Hydrologic data

Stream flow from seven of the selected watersheds is continuously measured by recording gages. The lengths of record for these seven recording gages are seven to fifteen years. Crest-stage-gages are used for the other two watersheds, with seven and eight years of record. The annual momentary peak discharge for each year of record and each watershed was obtained from the files of the Water Resources Division of the U. S. Geological Survey located in Rolla, Missouri. Ninety

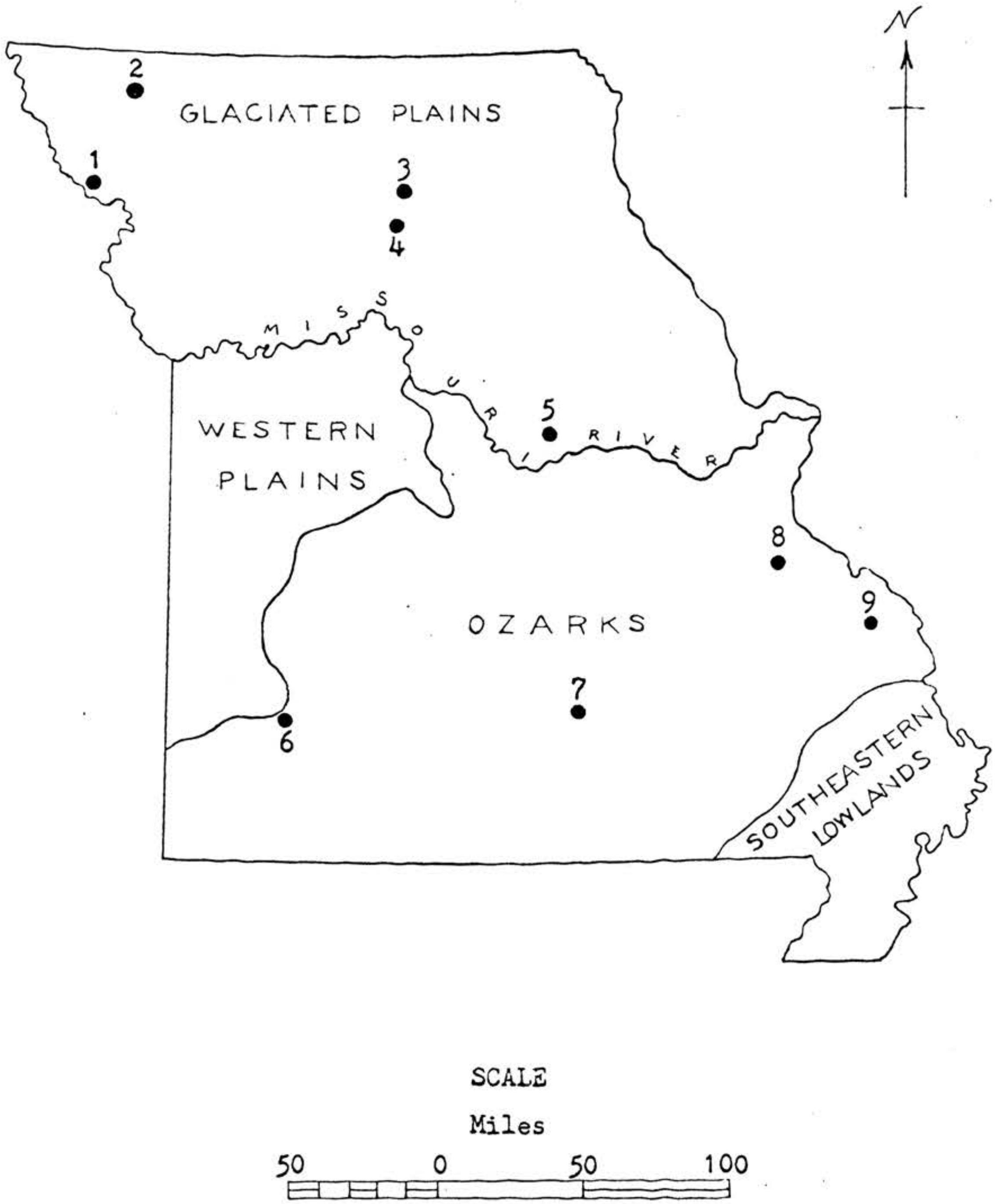

FIGURE 1. MAP SHOWING LOCATION OF WATERSHEDS.

Table 1. Watershed name, area, kind of gage, and years of record

Watershed Number		Watershed Name	Area sq. mile	Gage	Years Record
1	6-8160*	Mill Creek at Oregon, Mo.	5.07	Recording gage	14
2	6-8200	White Cloud Creek near Maryville, Mo.	6.18	do	15
3	6-9025	Hamilton Branch near New Boston, Mo.	2.51	do	8
4	6-9028	Onion Branch at St. Catherine, Mo.	1.04	Crest-stage-gage	9
5	6-9272	Big Hollow near Fulton, Mo.	4.05	Recording gage	7
6	7-1855	Stalh Creek near Miller, Mo.	3.95	do	14
7	7-0645	Big Creek near Yukon, Mo.	8.71	do	15
8	7-0175	Dry Branch near Bonne Terre, Mo.	3.41	do	8
9	7-0207	Hoehs Branch near Uniontown, Mo.	2.66	Crest-stage-gage	8

*U. S. G. S. Number

seven annual momentary peak discharges from 1949 to 1963 inclusive (Appendix I) were obtained and tabulated.

Mean annual peak stream discharge can be computed from the observed flood data. The mean annual peak discharge, designated $Q_{2.33}$, is the value which is equalled or exceeded on the average once in 2.33 years. Mean annual peak discharge of each watershed was obtained by graphical means from flood-frequency curves based upon Gumbel's theory of extreme values. The curves are plotted on paper developed by Powell (1943). The magnitude of annual momentary peak discharge is plotted on an arithmetic scale as the ordinate, and recurrence interval is plotted on the abscissa. A straight line representing frequency of recurrence was fitted by visual inspection through the plotted points. Harbaugh (1962, p. 135) has shown this method of plotting the frequency curve. Frequency curves of watersheds plotted in this study differ from those for the same watersheds in Harbaugh's study because the difference in number of years of record causes differences in plotting position of each annual peak discharge. The frequency curves used in this thesis are shown in Appendix VIII.

Precipitation is a primary factor affecting the magnitude of flood peak discharge. To study its effect, precipitation associated with each annual flood was determined. The watersheds which have recording gages also have rain gages located in the basins. For the two crest-stage-gage watersheds, the amount of precipitation was determined from the average of three rain gages located nearby. Storm rainfall data were obtained from Climatological Data for the State of Missouri (1949-1963) published by the U. S. Weather Bureau and from the files of rain charts of the U. S. Geological Survey, Water Resources Division, at Rolla. The date and time of the annual maximum momentary discharge is known for each watershed. From these data the precipitation of the twenty-four-hour and forty-eight-hour preceeding the time of the maximum momentary discharge was determined. These rainfall values are listed in Appendix I.

3. Soil groups

The distribution and characteristics of soil types within each watershed, as shown in Appendix III and in Appendix IV respectively, were obtained from soil survey reports and maps of the counties in Missouri published by the Soil Conservation Service, U. S. Department of Agriculture (1913-1953) and the Geology and Soils Manual (1962) published by the Missouri State Highway Commission. The boundaries of the watersheds were traced on soil maps. The areas of each soil type within each watershed was measured by a polar planimeter. These areas were compiled as percentages of each watershed's total area.

Soils of these nine watersheds are classified into thirty one named types. Not all of these soil types occurred in every watershed. In statistical analysis it is impossible to solve a problem having a number of independent variables greater than the number of observations. In order to reduce the number, these soil types were combined primarily on the basis of their texture and partly on a subjective estimate of soil infiltration capacity and soil moisture permeability. The soil types were combined into four groups as shown in Table 2. The approximate textural composition of soil types in these watersheds was derived from the Geology and Soils Manual (1962) and is shown in Appendix V.

Table 2. Percentage of watershed area covered by soil textural groups

Watershed Number	Sandy loam and Loam	Gravelly loam and Stony loam	Gravelly silt loam	Silty loam and Stony clay
1	-	-	-	100.0
2	-	-	-	100.0
3	87.5	-	-	12.5
4	100.0	-	-	-
5	3.4	0.05	-	96.55
6	-	6.1	54.6	39.3
7	-	92.0	-	8.0
8	-	-	-	100.0
9	-	-	-	100.0

4. Vegetal categories

Distribution and type of vegetal cover is one of the watershed characteristics governing the amount and rate of runoff. For this study, vegetal types and areas covered by each type were determined and outlined on the U. S. Department of Agriculture aerial photographs of 1959 to 1963 dates. The area covered by each type was measured with a polar planimeter and was compiled as a percentage of each watershed's total area (Appendix VI).

The vegetal types of each watershed were grouped into four categories: forest, pasture, crop, and other. The classification is based upon the definitions given in Soil and Water (1962) published by the Agricultural Experiment Station, University of Missouri, as follows:

Forest: Lands at least 10 percent of which are stocked by forest trees of any size and capable to producing timber or other wood products, or capable of exerting an influence on the water supply.

Pasture: Land in grass or other long-term forage growth and which is used primarily for grazing. Pasture includes grassland, non-forested pasture, wild hay, and other grazing land with the exception of pasture in a crop rotation. It may contain shade trees or scattered timber trees with less than 10 percent canopy, but the principal plant cover is such as to identify its use primarily as permanent grazing land.

Crop: Land currently tilled, including cropland harvested, crop failure, idle cropland, land in cover crops or pastured, rotation pasture, the cropland being prepared for crops. Cropland includes all tame hay, land in vegetables, fruits, and nuts.

Other: Farmsteds, wildlife areas, built-up and urban areas, and other tracts not classified as crop, pasture or forest.

The percentage of each category covering each watershed is shown in Table 3.

5. Bedrock categories

The bedrock types underlying each watershed were obtained primarily from the Geologic Map of Missouri (1961). Some additional geologic details were obtained from reports and maps from the library of the Missouri Geological Survey and Water Resources at Rolla, Missouri.

Table 3. Percentage of watershed area covered by each vegetal category

Watershed Number	Forest	Pasture	Crop	Other
1	8.95	61.95	23.75	5.35
2	1.97	55.02	41.46	1.55
3	2.15	75.72	20.86	1.27
4	4.04	51.06	40.77	4.13
5	17.46	48.12	28.42	6.00
6	4.48	37.65	45.13	12.74
7	49.10	24.48	25.39	1.03
8	32.43	24.08	41.47	2.02
9	8.95	61.95	23.75	5.35

The Index of Geologic Maps of Missouri (1963) compiled by T. R. Beveridge and J. W. Koenig, shows the areas and reference numbers of the materials available for the State of Missouri. Information from logs of wells near some of the watersheds was used to supplement or support the identification of rock types under each watershed.

The formation names and lithologic characteristics of bedrock underlying these watersheds are shown in Appendix VII. To simplify computations, the several formation were grouped into three lithologic categories. Table 4 shows the percentage area of each watershed underlain by each bedrock type.

Table 4. Percentage of watershed area underlain by each bedrock type

Watershed Number	Dolomite	Limestone	Shale	Rock Formation
1	-	-	100.0	Severy shale*
2	-	50.0	50.0	Calhoun shale and Howard limestone*
3	-	100.0	-	Marmaton limestone*
4	-	100.0	-	Marmaton limestone*
5	-	100.0	-	Fort Scott limestone*
6	-	100.0	-	Burlington limestone
7	100.0	-	-	Cotter and Jefferson City dolomite
8	100.0	-	-	Bonneterre dolomite
9	-	100.0	-	Plattin limestone

* Bedrock is covered by 100-250 feet of glacial till

B. METHOD OF ANALYSIS

In this study it is assumed that the discharge from a watershed is a function of many independent variables. The relationships between the measured characteristics and momentary peak discharge per unit area were studied by statistical techniques of multiple correlation and multiple regression. Mode (1951, p. 233) defined correlation as the amount of similarity, in direction and degrees, of variations in corresponding pairs or sets of observations. Determining the degree of association between pairs of observations is the technique of simple correlation. For more than two variables the method of multiple correlation is used. The theory and computational procedures for this method are described in many textbooks of statistics (i.e., Dixon and Massey, 1957).

The method of multiple regression was used to obtain an equation for estimating or predicting the annual momentary peak discharge per unit area from the measured watershed characteristics. The regression equation is used, in statistical terminology, to designate numerically the straight line or plane used to estimate one variable from others. The equation of multiple linear regression is of the form

$$Q = K + b_1x_1 + b_2x_2 + \text{-----} + b_n x_n$$

where Q is the dependent variable, annual maximum momentary discharge in cfs per sq. mile; K is a calculated constant; x_1, x_2, --- x_n are dependent variables such as precipitation, percent of soil groups, vegetal categories, and bedrock categories; and b_1, b_2, --- b_n are the regression coefficients.

The coefficient of correlation is the degree of associations between two variables. The coefficient of correlation, r, numerically never exceeds 1 (Mode, p. 240). The sign of r is always taken as that of the slope of the regression equation. The correlation can be positive or negative. It lies between the limits of -1 and +1. A high absolute value of r indicates a high degree of association. When its absolute value is 1, the relationship is perfect. When r = 0, the variables are independent.

Multiple correlation and regression for this study were computed with an electronic digital computer. The data were analysed by a program designated STAT02 which had been written previously by the UMR Computer Center Staff. Program STAT02 is titled "Least Squares Regression by Orthgonal Linear Functions Using the Choleski (Ralston and Wilf, 1962) Method." This program provides a least square fit between one dependent variable and a set of independent variables. It also provides the calculation of means, standard deviations, intercorrelations, a test of significance for each regression coefficient, and the calculation of the predicted value and residue for each data point. The program can handle a maximum of 45 independent variables with no practical limit on the number of observations.

Harbaugh (1962, p. 68) had found that the magnitude of mean annual discharge varied with the size and topography of the watershed. Because the objective of this present study was to determine the effect of other watershed characteristics, the effect of area was removed by using discharge per unit area. Because the small number of watersheds used in this study would have provided only nine values of mean annual discharge, the annual momentary peak discharge per unit area was used.

Five years of records, from 1959 through 1963, were used for the observation data. This period corresponds to the dates of available mosaic aerial photographs from which vegetal categories were determined. From known date and time of the annual maximum momentary discharge, the twenty-four-hour and forty-eight-hour rainfall preceeding the maximum momentary discharge were tabulated. Precipitation records for one momentary peak discharge from each of Watersheds No. 8 and 9 were not available, so the total number of sets of data was forty three instead of forty five.

C. RESULTS OF MULTIPLE CORRELATIONS

Multiple correlation between seventeen variables which consist of annual maximum momentary discharge in cfs per sq. mile, dependent variable, twenty-four-hour and forty-eight-hour antecedent rainfall in inches, four vegetal categories in percent, seven soil types in percent, and three bedrock categories in percent were computed. The results of this test showed no meaning because too many variables caused interrelation between independent variables. This statistical error will be reduced by decreasing the number of variables.

Among the four categories of vegetal cover described in the preceeding chapter, forest was expected to have the most effect on discharge. To reduce the number of variables, forest was retained as an independent variable whereas the other three, pasture, crop, and other, were grouped and named non-forest. With this change, twelve variables, including discharge, the dependent variable, were correlated. These variable names and units of measurement are listed in Table 5.

Table 5. Variables used in multiple correlations

Name	Units
Annual maximum momentary discharge per unit area	cfs/sq. mile
Twenty-four-hour antecedent precipitation	inches
Forty-eight-hour antecedent precipitation	inches
Forest	percent
Non-forest	do
Sandy loam and loam	do
Gravelly and stony loam	do
Gravelly silt loam	do
Silty loam and stony clay	do
Dolomite	do
Limestone	do
Shale	do

Output of this test did not give accurate results because Choleski's method of least squares regression used in this program becomes unstable when ten or greater number of variables are entered into the regression. The twelve variables and forty three observations apparently caused instability from the accumulation of roundoff error. However, the determination of regression coefficient significance by t-test showed that the following independent variables are significant in the regression equation: twenty-four-hour and forty-eight-hour antecedent rainfall; percent forest; percent gravelly and stony loam; and percent sandy loam and loam.

Simple correlations between discharge, the dependent variable, and twenty-four-hour and forty-eight-hour antecedent rainfall, the independent variables, were +0.40 and +0.38 respectively. Highly significant simple correlation, +0.91, was found between the independent variables, twenty-four-hour and forty-eight-hour antecedent rainfall. This high inter-relation of supposedly independent variables caused statistical error, so that forty-eight-hour antecedent rainfall was eliminated for the next tests.

To reduce the difficulties arising from roundoff errors, and to eliminate independent variables which had no significant effect in the data being tested, four three-variable multiple correlations were computed. This was done to determine which combination of three variables would give the highest correlation coefficient. Because it was apparent from the previous seventeen- and twelve-variable correlations that twenty-four-hour antecedent precipitation had the largest influence on annual peak discharge per unit area, this variable was included in all the smaller correlation studies. The forty-eight-hour antecedent precipitation was omitted because of its high correlation with twenty-four-hour antecedent precipitation. The three-variable regression equations were computed with peak discharge per unit area as dependent variable, and independent variables of twenty-four-hour antecedent precipitation and, successively, percent forest, percent gravelly and stony loam, percent sandy loam and loam, and percent dolomite.

In these equations, the "constant" first term in the regression equation was approximately 100. In one instance it was found to be much smaller. Further analysis revealed that a moderately high correlation occurred in the data between precipitation and percent of sandy loam and loam. The unanticipated correlation (0.453) of these physically non-related variables was greater than the simple correlation (0.402) between the precipitation and peak discharge. This coincidental correlation eliminated percent sandy loam and loam from consideration as a reliable predictor. A second problem found in this set of equations resulted from the extreme variation in the percent of gravelly and stony loam. Although most of the watersheds had no gravelly and stony loam, ninety two percent of one was covered by this soil category. Consequently, the standard deviation of the variable was much larger than its mean, and its distribution was not even approximately normal. This extreme departure from the assumptions required in multiple correlation made this variable unuseable.

After elimination of the two unuseable variable, it appeared that the percent of area covered by forest explained more (multiple correlation coefficient 0.413) of the variation in peak discharge than did percent area of dolomite (multiple correlation coefficient 0.408). As expected neither of these correlations was significant. The combined influence of other variables not included in the equations exceeded that of the variables tested.

A final set of regression equations using four variables was computed. As in previous computations, the annual maximum momentary peak discharge per unit area was the dependent variable. Twenty-four-hour antecedent precipitation and percentage of watershed covered by forest were used as independent variables with, successively, percent area of gravelly and stony loam, percent area of sandy loam and loam, and percent area of dolomite. Simple correlation coefficients between variables, computed as part of the multiple correlation procedure, revealed interdependence which invalidated the assumptions of the multiple correlation. A simple correlation coefficient of 0.92 was found between percent forest and percent dolomite, of 0.81 between percent forest and percent gravelly and stony loam, and of -0.39 between percent forest and sandy loam and loam. The cause of these correlations is readily understandable from the agricultural practices and geology of the region. In Missouri, most of the dolomite contains abundant nodules, lenses, and layers of chert. The clayey soils formed by the weathering of these cherty dolomites contain a large percentage of chert gravel, little sand, are very difficult to plow, and tend to be relatively infertile. Consequently, the watersheds underlain by dolomite tend to have gravelly and stony soils which are used agriculturally only for forest land. Watersheds underlain by shale and limestone tend to have loamy or sandy loam soils which are usually planted to pasture or crops.

Because of the inter-relationship of forest, dolomite, and stony loam the four-variable correlations are valuable primarily as indications of which combination of variables might be most fruitful for future investigation. Future study may reveal some as yet unidentified factor to which percent forest, dolomite, and stony loam are all related and which would be a better predictor of peak discharge than any of these. It is hoped that factor analysis of a larger sample of watersheds may identify this unknown factor.

The results of the four-variable correlations are shown in Table 6. The constant term in the correlations with percent stony loam and percent dolomite is approximately 110 with a large standard deviation of approximately 52. The coefficients of the antecedent rainfall and percent forest variables are, respectively, 61 and -1.6 with standard deviation of 22 and 3. The coefficient for antecedent rainfall is highly significant, and gives, even with this small sample of watersheds, a good estimate of the magnitude of the coefficient to be expected from a much larger sample. The negative sign of the coefficient of percent forest is as was expected from previous work. The large standard deviation of this coefficient indicates that little reliability should be placed on this estimate. The correlation with percent sandy loam has been included to show the effect of the coincidental correlation between precipitation and the supposedly independent percent sandy loam. This coincidental relationship caused an order-of-magnitude change in the constant term and changed the sign of the coefficient of percent forest. Little significance should be attached to the computed correlation coefficients, because of departures from the conditions required for correlation and regression analysis. The computed values have been included to show that, for this sample of watersheds, the variables listed do account for some of the variations in annual momentary peak discharge.

Table 6. Regression coefficients, standard deviation coefficients, multiple correlation coefficients, and simple correlation with peak discharge; and estimated discharge equations

X_i	b_i	S_b	r_{yx}	b_i	S_b	r_{yx}	b_i	S_b	r_{yx}
X_1	61.81	22.18	0.402	61.36	22.20	0.402	88.08	23.64	0.402
X_2	-1.563	2.392	-0.081	-1.872	3.60	-0.081	0.493	1.431	-0.081
$X_{3.1}$	0.424	1.274	-0.044						
$X_{3.2}$				0.394	1.369	-0.052			
$X_{3.3}$							1.484	0.632	0.113
K	111.0	51.82		112.8	54.16		3.988	64.57	
r	0.4156			0.4150			0.5226		

Estimated discharge equations:

$$Q = 111.0 + 61.8\ x_1 - 1.6\ x_2 + 0.4\ x_{3.1} \tag{1}$$

$$Q = 112.8 + 61.4\ x_1 - 1.9\ x_2 + 0.4\ x_{3.2} \tag{2}$$

$$Q = 4.0 + 88.1\ x_1 + 0.5\ x_2 + 1.5\ x_{3.3} \tag{3}$$

where

Q = peak discharge, cfs/sq. mile

x_1 = twenty-four-hour antecedent rainfall, inches

x_2 = forest, percent

$x_{3.1}$ = gravelly and stony loam, percent

$x_{3.2}$ = dolomite, percent

$x_{3.3}$ = sandy loam and loam, percent

D. IMPROVED ESTIMATION OF MEAN ANNUAL FLOODS

Equations for estimating mean annual discharge from small watersheds had been derived perviously by Harbaugh (1962, pp. 68-69). His equations utilized a factor which he called "basin index." The "basin index" is derived from the topographic characteristics of area, length and slope. Harbaugh's equations are shown in Table 7.

Table 7. Relationship of mean annual flood to "basin index", from Harbaugh (p. 68), Table IX

Drainage Area	Relationship
0 to 0.5 sq. mile	$MAF = 462(AL^2S^{1/8})^{0.30}$
0.5 to 1.5 sq. miles	$MAF = 210(AL^2S^{1/8})^{0.65}$
1.5 to 10.0 sq. miles	$MAF = 113(AL^2S^{1/2})$

where A = drainage area in square miles

L = length of basin in miles

SL = slope of basin in feet per foot

Harbaugh (1962) had summarized that vegetal cover would have an effect on discharge: "The effect of cover has been noted by Potter as having an effect upon runoff (p. 57)." "This variation (of runoff from drainage areas of less than 1.5 sq. miles) could be expected .... (as) the effect of cover on runoff becomes a factor (p. 61)." However, he thought that topographic slope would be an adequate index of land use: "The fact that pasture land is not steep, and that most forested areas are not in the bottomlands, led the writer to believe definition of slope would adequately account for cover (p. 61)."

Because percent of watershed area covered by forest was found to be significantly related to annual peak momentary discharge, it was investigated in the present study for its effect on mean annual discharge. Measured mean annual discharge was determined from the flood frequency curves (Appendix VIII) for each of the watersheds in this study. The length, slope, and area of the nine watersheds used in the present study were measured according to the procedure described by Harbaugh (pp. 54, 57). In particular, watershed length was measured with dividers along the meanders of the main stream. Harbaugh(p. 57) used dividers with a minimum increment of 0.1 mile. Minimum increment used in the present study was slightly less than 0.1 mile.

Some ambiguity exists about the point which Harbaugh used for the upper end of his channel length. His length was "based upon the elevations of the farthest point from the outlet .... (p. 54)," but he does not say whether this is on the basin divide or the farthest point indicated by V-shaped contours. He says that "the length of the stream should be measured .... using the end of the V-shaped contours rather than ceasing at the end of the streams printed blue (p. 57)," and to "determine the length of the basin by measuring with dividers the stream along its meander from the outlet to the farthest point in the basin (p. 68)." In several of the watersheds in the present study there were one or more rounded contours, without V's, between the highest or "farthest" V and the watershed divide. In the present study the length was measured along the channel extended headward, normal to the contours, to the watershed divide. Some differences were found between the values given by Harbaugh and those measured in the present study (Appendix IX). In one case, Watershed No. 9, the discrepancy was so large that this watershed was omitted from the following analysis.

After measurement of watershed area, length, and slope, the estimated mean annual flood was calculated from the equations given by Harbaugh (Table 7, above).

The effectiveness of percent of forest cover in improving the estimate of mean annual runoff was tested by simple correlations between the difference between estimated and measured mean annual flood and the percent forest cover. The numerical value of the coefficient of simple correlation for this relation was -0.465. The negative sign means that as percent forest increases the difference decreases. The relation was found to be :

$$D = 54 - 0.7\ F$$

where D is the difference between estimated and measured mean annual flood, cfs/sq. mile, and F is percent of watershed area covered by forest. The coefficient of determination (which is the square of the coefficient of correlation) was found to be 0.22, which indicates that 22 percent of the difference between estimated and measured mean annual flood per square mile can be explained by percent forest cover. The average percentage of forest for watersheds which were studied by Harbaugh may be determined from the above equation by giving D equal to zero. Then, F would be about 77 percent. These results indicate that Harbaugh's equations would be improved by adding "+54 - 0.7 (percent forest)" to each equation.

IV

CONCLUSIONS

Factors affecting annual momentary peak discharge and mean annual discharge from nine small watersheds in Missouri were studied by means of multiple correlation and regression analysis. Antecedent precipitation, watershed vegetal cover, soil, and rock type were correlated with forty three measurements of annual momentary peak discharge. The multiple correlation coefficient between annual momentary peak discharge, twenty-four-hour antecedent precipitation, percent forest, and percent gravelly and stony loam was 0.416. Some coincidental relationships which occurred between independent variables invalidated assumptions in the statistical analysis and caused inaccuracies in the regression equations. Simple and multiple correlation coefficients between annual momentary peak discharge and independent variables indicate that twenty-four-hour antecedent rainfall is a highly significant independent variable and that percent forest cover may be significant in estimating discharge. The expected negative sign of the simple correlation coefficient between annual momentary peak discharge and percent forest was found in this study.

Simple correlation and regression analysis between percent forest cover and the difference between mean annual flows obtained from frequency curves in this study and mean annual flows estimated by equations developed by Harbaugh showed that Harbaugh's equations were designed for watersheds of 77 % average forest cover. The coefficient of determination and the coefficient of simple correlation of this difference with percent forest were found to be 0.22 and -0.465 respectively. From the regression equation it was apparent that

Harbaugh's equations would be improved by adding "+54 - 0.7 (percent forest)" to each equation.

The wide range of variation in data values, and unforeseen inter-correlation of independent variables, caused errors in statistical computation. A future study is recommended, with a larger size sample, to correct these errors. This study has been useful in indicating which factors may be the most significant variables in future equations for estimating momentary and mean annual peak discharge from small watersheds.

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APPENDIX I. GAGING STATION DESCRIPTION, HYDROLOGIC DATA, PRECIPITATION DATA AND FLOOD RECURRENCE INTERVAL

Watershed No. 1 6-8160 Mill Creek at Oregon, Mo.

Drainage area 5.07 sq. miles; $Q_{2.33}$ 860 cfs.

Recording gage location Lat. 39°58'55", long. 95°07'35", in NE¼NE¼ sec. 35, T. 60 N., R. 38 W., on left bank 15 feet downstream from bridge on U. S. Highway 275, 0.5 mile upstream from Rock Creek, 1 mile southeast of Oregon, Holt County, Mo.

Rain gage location Lat. 39°59'25", long. 95°07'45", in NW¼SE¼ sec. 26, T. 60 N., R. 38 W.

Water Year	Date	Maximum Momentary Discharge cfs	24-hour Antecedent Precipitation in.	48-hour Antecedent Precipitation in.	Order Number	Recurrence Interval
1950	Aug. 15	780	1.30	1.61	4	3.75
1951	March 2	840	1.90	1.90	3	5
1952	Nov. 12	194	1.65	1.65	13	1.15
1953	Nov. 17	78	1.44	1.44	14	1.07
1954	Aug. 21	590	1.13	1.13	9	1.67
1955	June 24	706	1.70	1.70	8	1.88
1956	July 2	417	2.10	2.10	11	1.36
1957	June 14	381	1.04	1.36	12	1.25
1958	July 30	2,640	1.75	1.75	2	7.5
1959	June 29	500	1.90	2.80	10	1.5
1960	June 30	739	1.15	1.15	6	2.5
1961	Sept. 3	2,730	4.16	4.35	1	15
1962	May 28	750	3.48	3.48	5	3
1963	May 16	722	1.60	2.80	7	2.14

APPENDIX I. (cont.) Hydrologic data

Watershed No. 2 6-8200 White Cloud Creek near Maryville, Mo.

Drainage area 6.18 sq. miles; $Q_{2.33}$ 1000 cfs.

Recording gage location Lat. 40°23'22", long. 94°54'33", in NW¼NW¼ sec. 1, T. 64 N., R. 36 W., at bridge on U. S. Highway 71, 4.5 miles northwest of Maryville, Nodaway County, Mo.

Rain gage location Lat. 40°25'50", long. 94°53'30", in NE¼NE¼ sec. 24, T. 65 N., R. 36 W.

Water Year	Date	Maximum Momentary Discharge cfs	24-hour Antecedent Precipitation in.	48-hour Antecedent Precipitation in.	Order Number	Recurrence Interval
1949	June 1	4,100	4.68	4.68	1	16
1950	July 17	328	2.54	2.54	11	1.45
1951	April 30	920	1.89	2.17	7	2.29
1952	June 21	1,610	4.64	4.64	3	5.33
1953	April 30	107	0.89	0.92	14	1.14
1954	May 31	256	1.18	2.13	12	1.33
1955	April 13	900	4.35	4.88	8	2
1956	July 7	395	1.22	1.22	10	1.6
1957	April 3	169	1.82	1.85	13	1.23
1958	July 19	2,300	3.45	3.90	2	8
1959	May 30	1,430	2.37	3.12	6	2.67
1960	May 16	1,540	2.62	2.62	4	4
1961	Sept. 12	1,460	2.95	3.29	5	3.2
1962	May 28	860	3.06	3.30	9	1.78
1963	May 15	102	1.40	1.40	15	1.07

APPENDIX I. (cont.) Hydrologic data

Watershed No. 3 6-9025 Hamilton Branch near New Boston, Mo.

Drainage area 2.51 sq. miles; $Q_{2.33}$ 520 cfs.

Recording gage location Lat. 39°57'08", long. 92°54'08", in SE¼SW¼ sec. 3, T. 59 N., R. 18 W., at bridge on State Highway 11, 0.5 mile upstream from New Boston Branch, 2.25 miles west of New Boston, Linn County, Mo.

Rain gage location Lat. 39°57'45", long. 92°54'23", in SW¼NW¼ sec. 3, T. 59 N., R. 18 W.

Water Year	Date	Maximum Momentary Discharge cfs	24-hour Antecedent Precipitation in.	48-hour Antecedent Precipitation in.	Order Number	Recurrence Interval
1956	Aug. 2	612	2.07	2.07	4	2.25
1957	July 29	520	1.30	1.40	5	1.8
1958	July 15	693	2.80	3.35	2	4.5
1959	Feb. 9	203	0.20	0.60	8	1.13
1960	June 30	800	2.10	2.10	1	9
1961	April 21	675	1.30	1.30	3	3
1962	Oct. 29	414	0.70	0.80	6	1.5
1963	March 4	232	0.85	0.85	7	1.29

APPENDIX I. (cont.) Hydrologic data

Watershed No. 4 6-9028 Onion Branch at St. Catherine, Mo.

Drainage area 1.04 sq. miles; $Q_{2.33}$ 350 cfs.

Crest-stage-gage location Lat. 39°47'46", long. 92°59'17", in NE¼SE¼ sec. 35, T. 58 N., R. 19 W., 0.3 mile northeast of St. Catherine, Linn County, Mo.

Rain gage location No rain gage in the watershed. Rainfall data were averaged from three nearly rain gages: Brookfield, lat. 39°47', long. 93°05', about 5 miles southeast of watershed; Linneus, lat. 39°50', long. 93°12', about 10 miles northwest of watershed; and Fountain Grove Wildlife, lat. 39°42', long. 93°18', about 15 miles southwest of watershed.

Water Year	Date	Maximum Momentary Discharge cfs	24-hour Antecedent Precipitation in.	48-hour Antecedent Precipitation in.	Order Number	Recurrence Interval
1955	June 25	285	2.15	3.28	5	2
1956	Oct. 5	78	1.89	3.76	8	1.25
1957	May 16	340	1.48	1.48	4	2.5
1958	July 15	982	7.89	8.51	1	10
1959	Sept. 23	410	1.97	1.97	3	3.33
1960	May 16	190	1.86	1.86	6	1.67
1961	July 25	725	1.75	1.76	2	5
1962	Oct. 29	120	0.20	0.82	7	1.43
1963	June 28	20	0.15	0.42	9	1.11

APPENDIX I. (cont.) Hydrologic data

Watershed No. 5 6-9272 Big Hollow near Fulton, Mo.

Drainage area 4.05 sq. miles; $Q_{2.33}$ 640 cfs.

Recording gage location Lat. 38°48'45", long. 91°56'45", in NW¼NW¼ sec. 33, T. 47 N., R. 9 W., at culvert on County Highway C, 2 miles south of Fulton, Callaway County, Mo.

Rain gage location Lat. 38°50'48", long. 91°58'36", in SW¼SE¼ sec. 18, T. 47 N., R. 9 W.

Water Year	Date	Maximum Momentary Discharge cfs	24-hour Antecedent Precipitation in.	48-hour Antecedent Precipitation in.	Order Number	Recurrence Interval
1957	June 29	616	1.6	1.7	5	1.6
1958	Aug. 1	936	0.5	2.45	1	8
1959	Oct. 9	936	2.35	2.35	2	4
1960	Oct. 10	638	2.05	2.05	4	2
1961	May 5	686	2.10	2.10	3	2.67
1962	Feb. 8	526	0.48	0.48	6	1.33
1963	May 17	104	1.15	2.40	7	1.14

APPENDIX I. (cont.) Hydrologic data

Watershed No. 6 7-1855 Stahl Creek near Miller, Mo.

Drainage area 3.95 sq. miles; $Q_{2.33}$ 700 cfs.

Recording gage location Lat. 37°11'40", long. 93°50'40", in SE¼ sec. 26, T. 29 N., R. 27 W., at bridge on State Highway 39, 1.5 miles south of Miller, Lawrence County, Mo.

Rain gage location Lat. 37°12', long. 93°51', in NE¼ sec. 26, T. 29 N., R. 26 W., 0.5 mile north of junction Highways 66 and 39.

Water Year	Date	Maximum Momentary Discharge cfs	24-hour Antecedent Precipitation in.	48-hour Antecedent Precipitation in.	Order Number	Recurrence Interval
1950	Aug. 27	745			7	2.14
1951	July 4	904	1.91	2.56	6	2.4
1952	Feb. 1	363	1.55	1.55	11	1.36
1953	March 14	133	1.57	1.59	14	1.07
1954	Sept. 29	250	2.05	2.05	13	1.15
1955	Oct. 25	497	1.90	1.98	9	1.67
1956	June 7	745	2.55	2.66	8	1.88
1957	July 1	929	1.81	2.14	5	3
1958	July 7	1,010	4.32	4.55	3	5
1959	Feb. 9	308	2.08	2.08	12	1.25
1960	Oct. 4	1,180	1.76	3.61	2	7.5
1961	July 7	1,430	2.15	2.46	1	15
1962	June 10	482	1.55	1.79	10	1.5
1963	May 13	1,000	4.65	4.65	4	3.75

APPENDIX I. (cont.) Hydrologic data

Watershed No. 7 7-0645 Big Creek near Yukon, Mo.

Drainage area 8.71 sq. miles; $Q_{2.33}$ 1800 cfs.

Recording gage location Lat. 37°14'00", long. 91°51'00", in SW¼NW¼ sec. 5, T. 29 N., R. 8 W., at bridge on State Highway 137, 3 miles south of Yukon, Texas County, Mo.

Rain gage location Lat. 37°13'36", long. 91°52'31", in S½ sec. 1, T. 29 N., R. 9 W., 1.7 miles north of Tyrone, Mo.

Water Year	Date	Maximum Momentary Discharge cfs	24-hour Antecedent Precipitation in.	48-hour Antecedent Precipitation in.	Order Number	Recurrence Interval
1949	July 7	3,510	3.25		3	5.33
1950	May 10	3,120	2.96	3.01	4	4
1951	June 30	2,950	3.17	3.50	5	3.2
1952	Oct. 27	1,140	1.35	1.35	9	1.78
1953	March 3	475	1.20	1.41	14	1.14
1954	March 25	462	1.00	1.73	15	1.07
1955	March 20	895	2.09	2.09	11	1.45
1956	May 15	4,860	3.75	4.90	1	16
1957	May 18	1,430	0.68	1.74	7	2.29
1958	Dec. 17	2,480	3.14	3.48	6	2.67
1959	Nov. 17	871	2.11	2.11	12	1.33
1960	Dec. 27	1,000	0.91	0.91	10	1.6
1961	May 7	4,780	1.99	2.45	2	8
1962	Sept. 30	561	2.01	2.01	13	1.23
1963	May 25	1,180	2.51	2.51	8	2

APPENDIX I. (cont.) Hydrologic data

Watershed No. 8 7-0175 Dry Branch near Bonne Terre, Mo.

Drainage area 3.41 sq. miles; $Q_{2.33}$ 720 cfs.

Recording gage location Lat. 37°55'55", long. 90°27'40", at west central edge of Survey 3062, T. 37 N., R. 5 E., downstream side of highway bridge T-397 on County Highway K, 0.5 mile above Terre Bleue Creek, and 4.5 miles east of Bonne Terre, St. Francois County, Mo.

Rain gage location Lat. 37°56'36", long. 90°26'13", Survey 3062, T. 37 N., R. 5 E.

Water Year	Date	Maximum Momentary Discharge cfs	24-hour Antecedent Precipitation in.	48-hour Antecedent Precipitation in.	Order Number	Recurrence Interval
1956	June 24	670	1.25	1.35	4	2.25
1957	June 30	1,520	4.50	5.19	1	9
1958	July 17	409	1.30	2.10	7	1.29
1959	April 18	570	1.00	1.00	5	1.8
1960	Jan. 14	350			8	1.13
1961	June 14	730	2.10	2.10	3	3
1962	Sept. 14	910	3.05	3.05	2	4.5
1963	June 10	530	2.25	2.25	6	1.5

APPENDIX I. (cont.) Hydrologic data

Watershed No. 9 7-0207 Hoehs Branch near Uniontown, Mo.

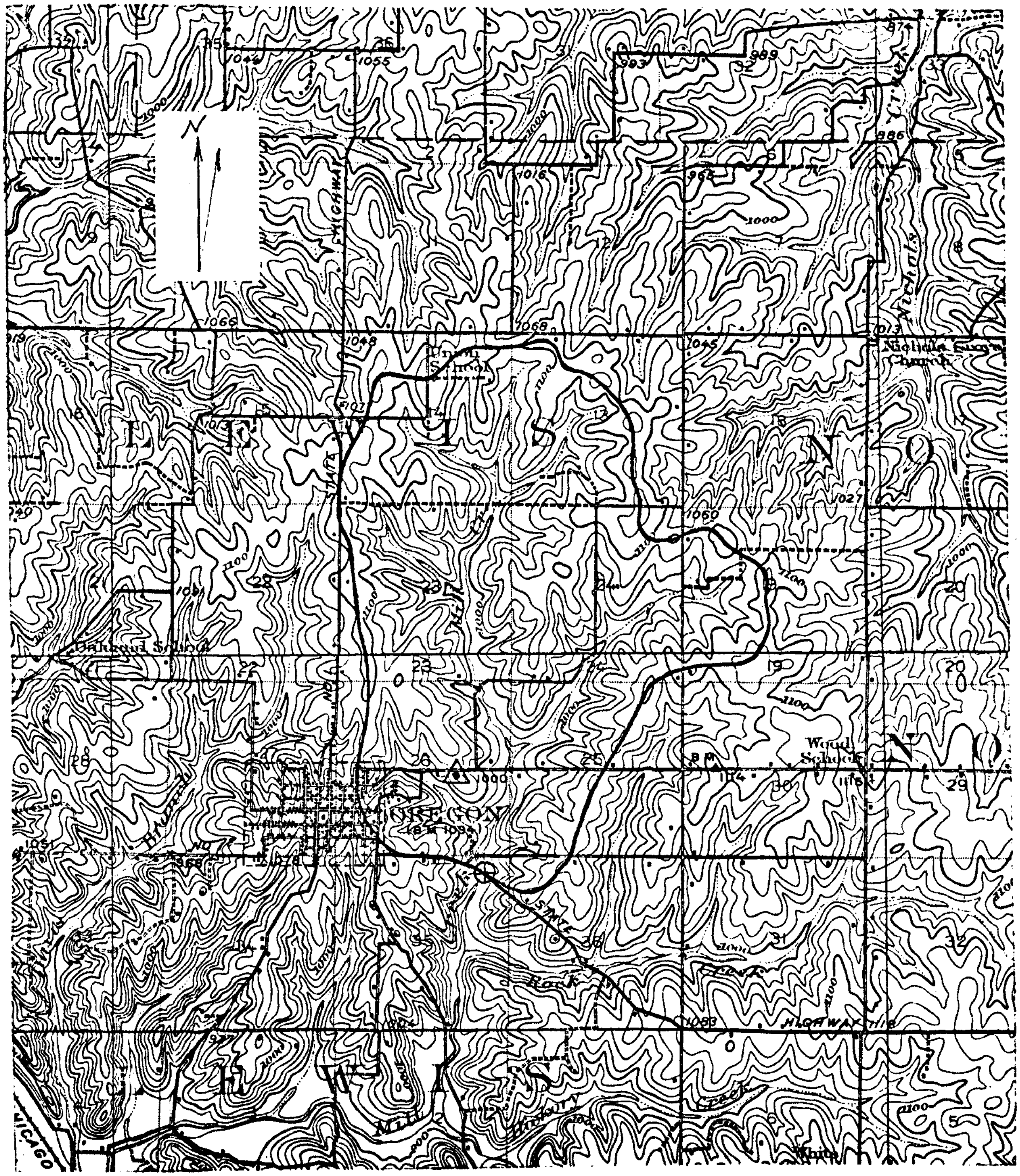
Drainage area 2.66 sq. miles; $Q_{2.33}$ 850 cfs.

Crest-stage-gage location Lat. 37°37'50", long. 89°43'50", in SW¼SE¼ sec. 20, T. 34 N., R. 12 E., 1.2 miles north of Uniontown, Perry County, Mo.

Rain gage location No rain gage in the watershed. Rainfall data were averaged from three nearby rain gages: Perryville, lat. 37°43', long. 89°52', about 9 miles northwest of watershed; Farmington, lat. 37°46', long. 90°24', about 20 miles northeast of watershed; and Jackson, lat. 37°23', long. 89°40', about 15 miles south of watershed.

Water Year	Date	Maximum Momentary Discharge cfs	24-hour Antecedent Precipitation in.	48-hour Antecedent Precipitation in.	Order Number	Recurrence Interval
1955	March 20	352	1.63	1.63	8	1.25
1956	May 14	1,400	0.40	0.40	1	10
1957	May 22	900	2.64	2.74	5	2
1958	Jan. 21	1,400	0.75	1.13	2	5
1959	Aug. 17	1,180	2.90	2.90	3	3.33
1960	Aug. 20	450	0.93	1.70	6	1.67
1961	June 15	1,000	1.95	2.28	4	2.5
1962	Jan. 22	420	1.85	1.99	7	1.43
1963		50				

APPENDIX II. WATERSHED TOPOGRAPHY AND GAGE LOCATION



Legend

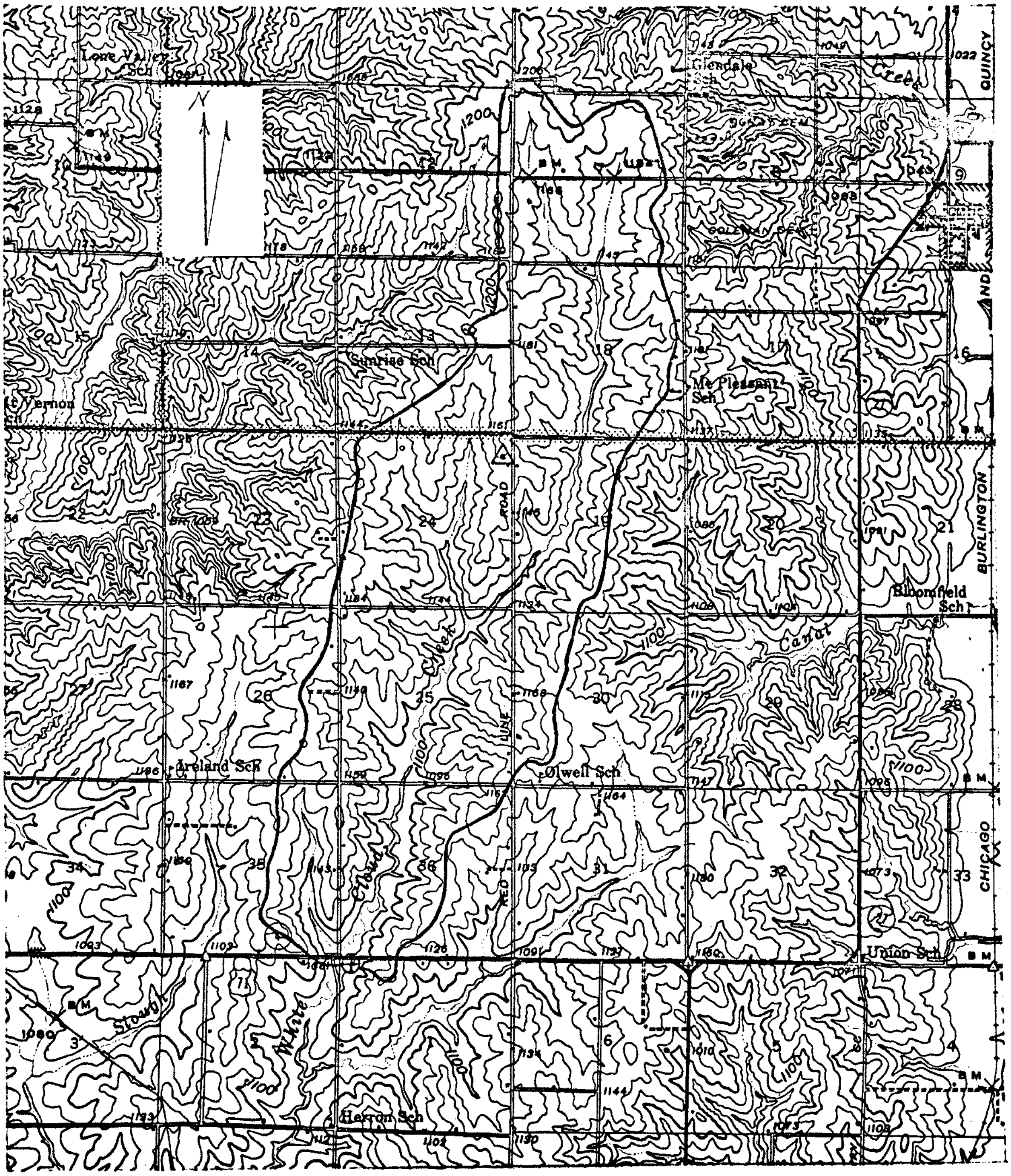
Maitland and Oregon Quadrangles
Scale 1:62500
Contour interval 20 feet
Area of watershed 5.07 sq. miles

⊕ Recording gage

△ Rain gage

Outline of Watershed No. 1

APPENDIX II. (cont.) Watershed topography



Maryville Quadrangle
Scale 1:62500
Contour interval 10 feet
Area of watershed 6.18 sq. miles

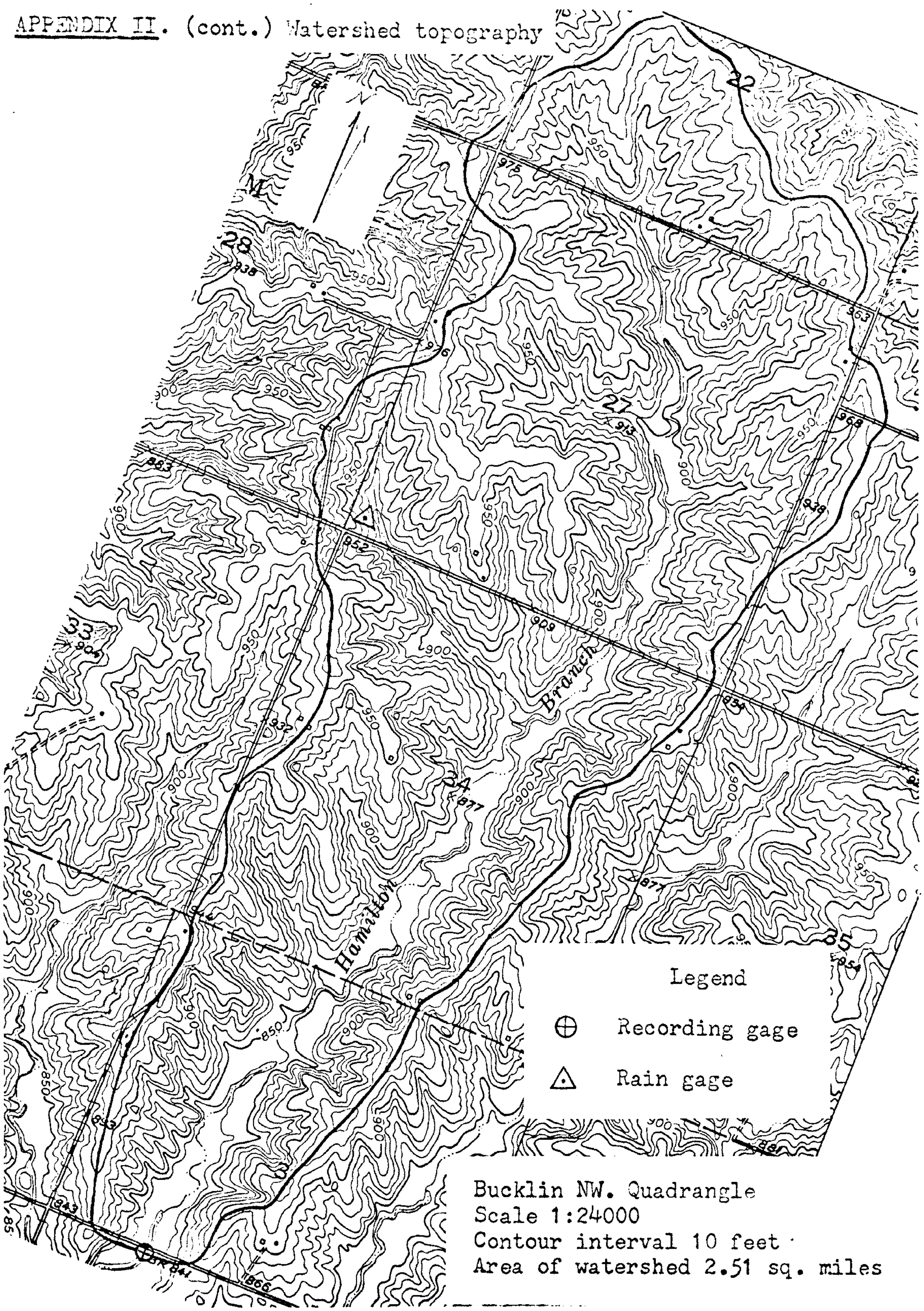
Legend

⊕ Recording gage

△ Rain gage

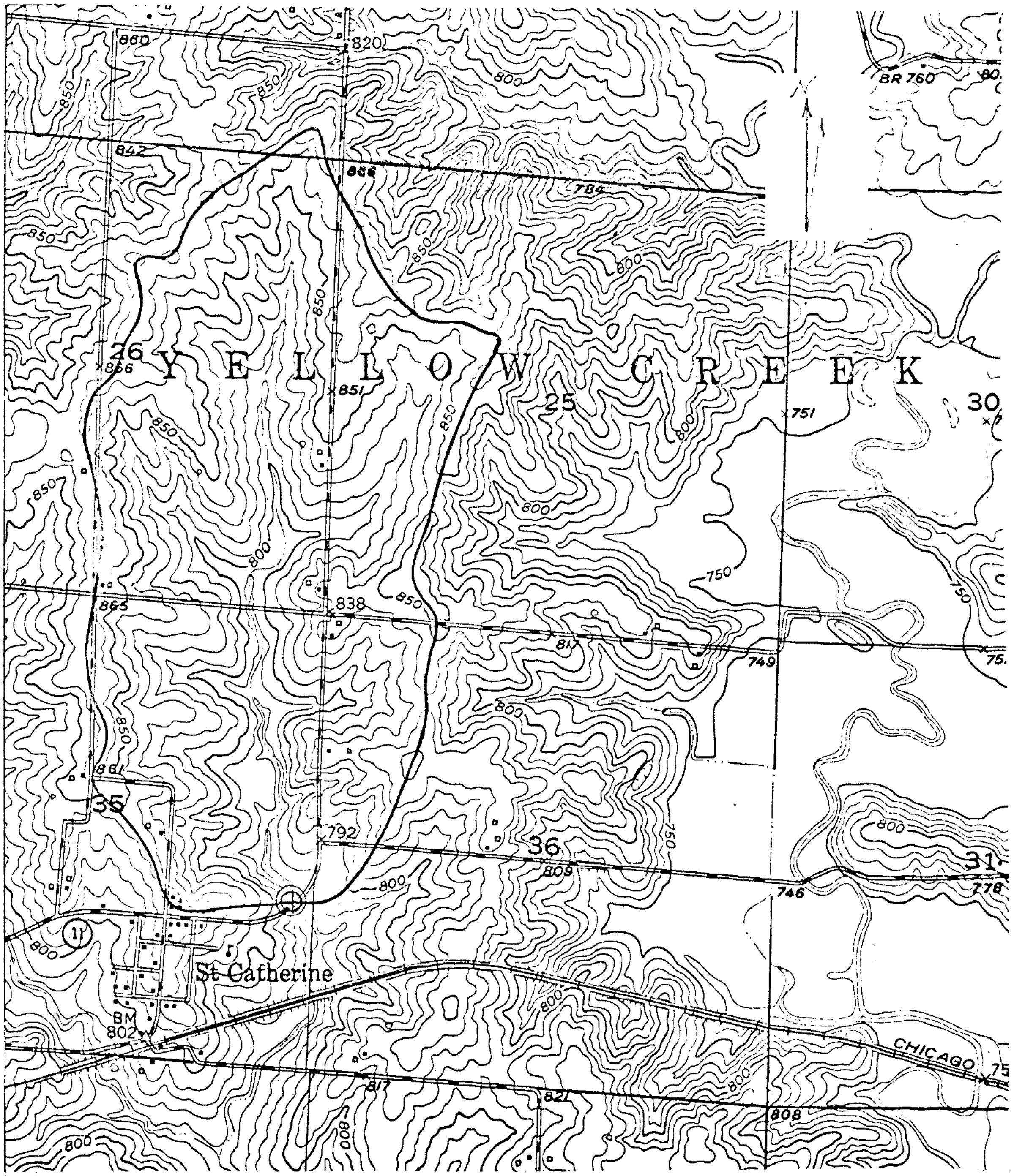
Outline of Watershed No. 2

APPENDIX II. (cont.) Watershed topography



Outline of Watershed No. 3

APPENDIX II. (cont.) Watershed topography



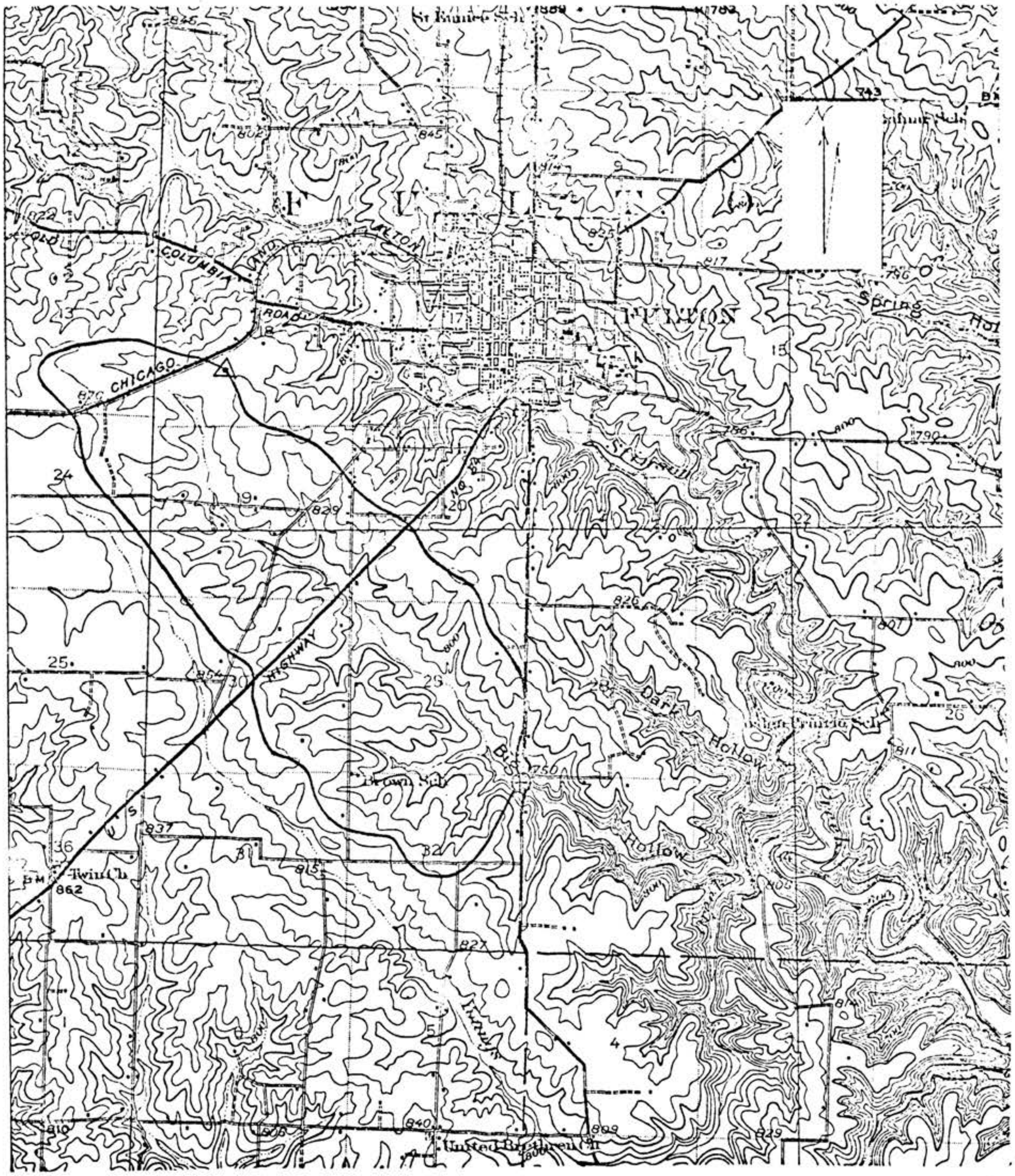
Legend

⊕ Crest-stage-gage

Bucklin Quadrangle
Scale 1:24000
Contour interval 10 feet
Area of watershed 1.04 sq. miles

Outline of Watershed No. 4

APPENDIX II. (cont.) Watershed topography



Legend

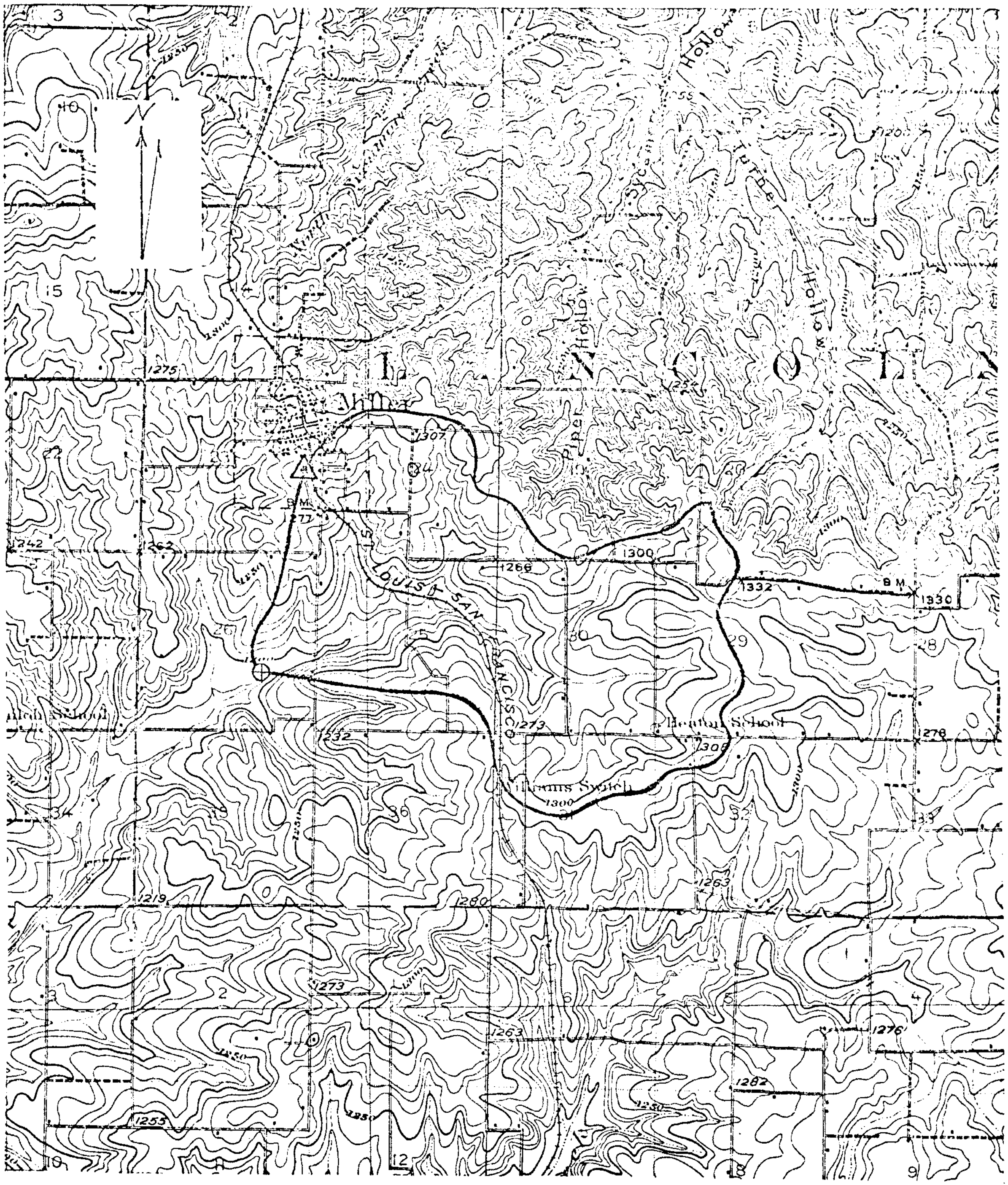
Fulton Quadrangle
Scale 1:62500
Contour interval 20 feet
Area of watershed 4.05 sq. miles

⊕ Recording gage

△ Rain gage

Outline of Watershed No. 5

APPENDIX II. (cont.) Watershed topography



Legend

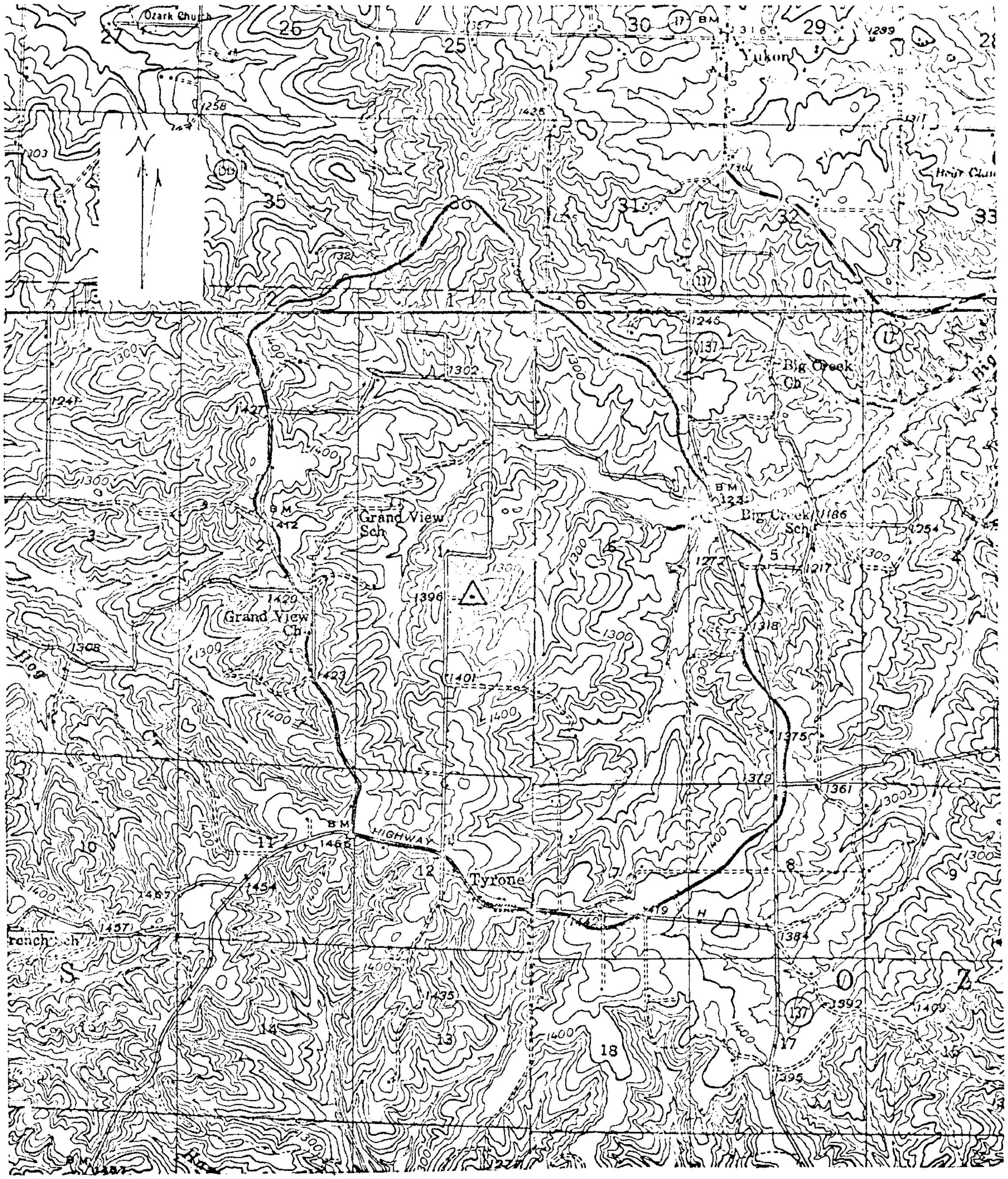
⊕ Recording gage

△ Rain gage

Scotts City Quadrangle
Scale 1:62500
Contour interval 10 feet
Area of watershed 3.95 sq. miles

Outline of Watershed No. 6

APPENDIX II. (cont.) Watershed topography



Legend

⊕ Recording gage

△ Rain gage

Raymondville and Clear Springs Quadrangles
Scale 1:62500
Contour interval 20 feet
Area of watershed 8.71 sq. miles

Outline of Watershed No. 7

APPENDIX II. (cont.) Watershed topography

Legend

⊕ Recording gage

△ Rain gage

Farmington Quadrangle
Scale 1:62500
Contour interval 20 feet
Area of watershed 3.41 sq. miles

Outline of Watershed No. 8

APPENDIX II. (cont.) Watershed topography

Legend

⊕ Crest-stage-gage

Perryville and Altenburg Quadrangles
Scale 1:62500
Contour interval 20 feet
Area of watershed 2.66 sq. miles

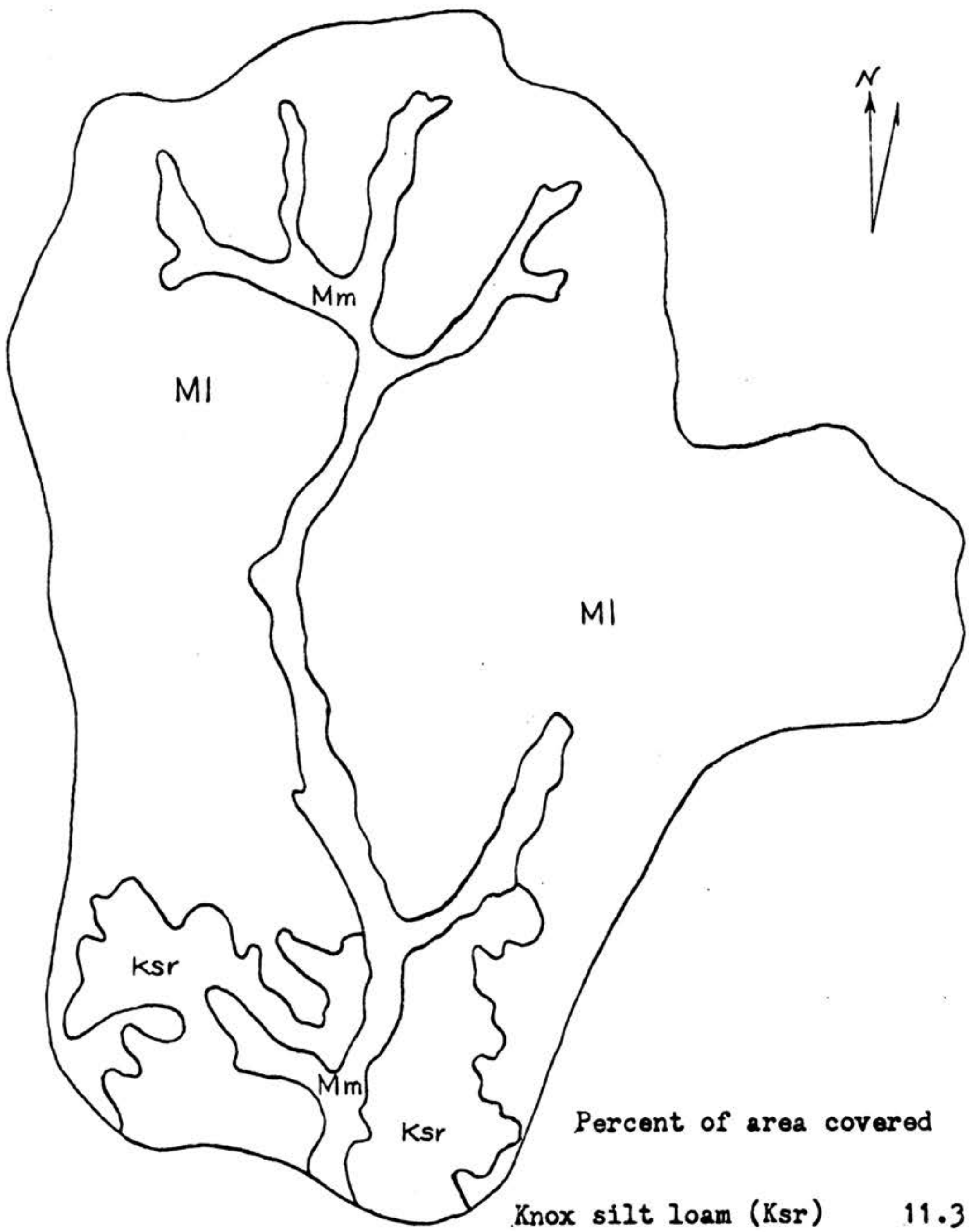
Outline of Watershed No. 9

APPENDIX III

MAPS SHOWING DISTRIBUTION AND PERCENTAGE OF WATERSHED AREAS COVERED

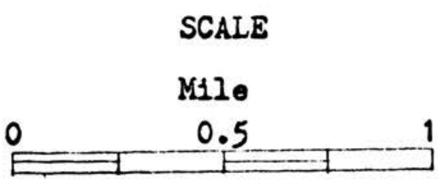
BY

SOIL TYPES



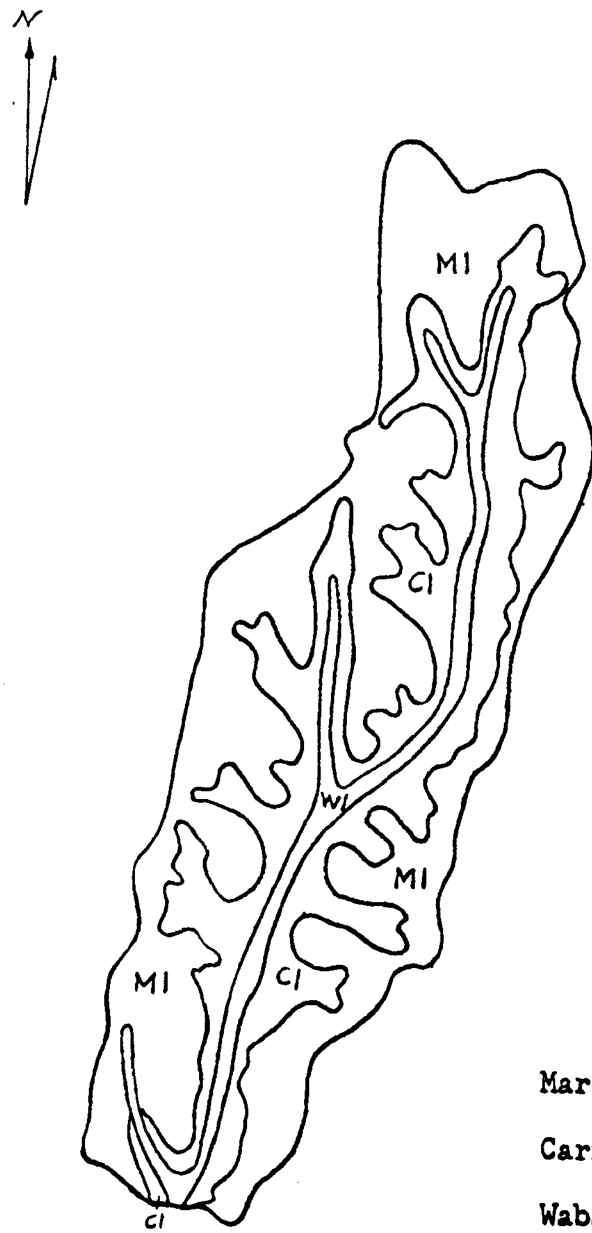
Percent of area covered

Knox silt loam (Ksr)	11.3 %
Marshall silt loam (Ml)	78.7 %
Mc Paul silt loam (Mm)	10.0 %



Distribution of soil types in Watershed No. 1

After Shrader, W. D., 1953



Percent of area covered

Marshall silt loam (Ml)	60.3 %
Carrington silt loam (Cl)	6.7 %
Wabash silt loam (Wl)	33.0 %

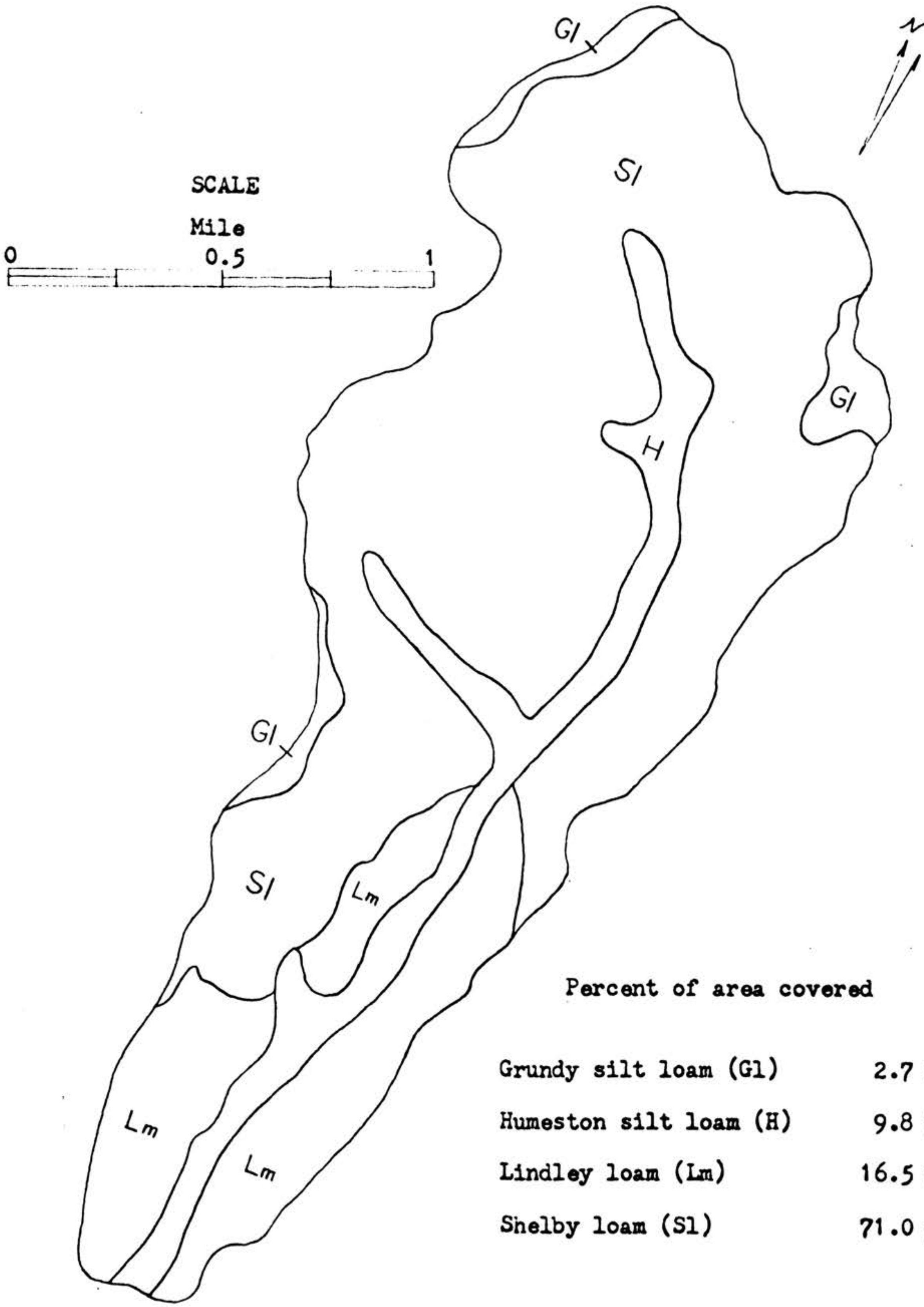
SCALE

Miles

0 0.5 1 2 3

Distribution of soil types in Watershed No. 2

After Vanatta, E. S., 1913

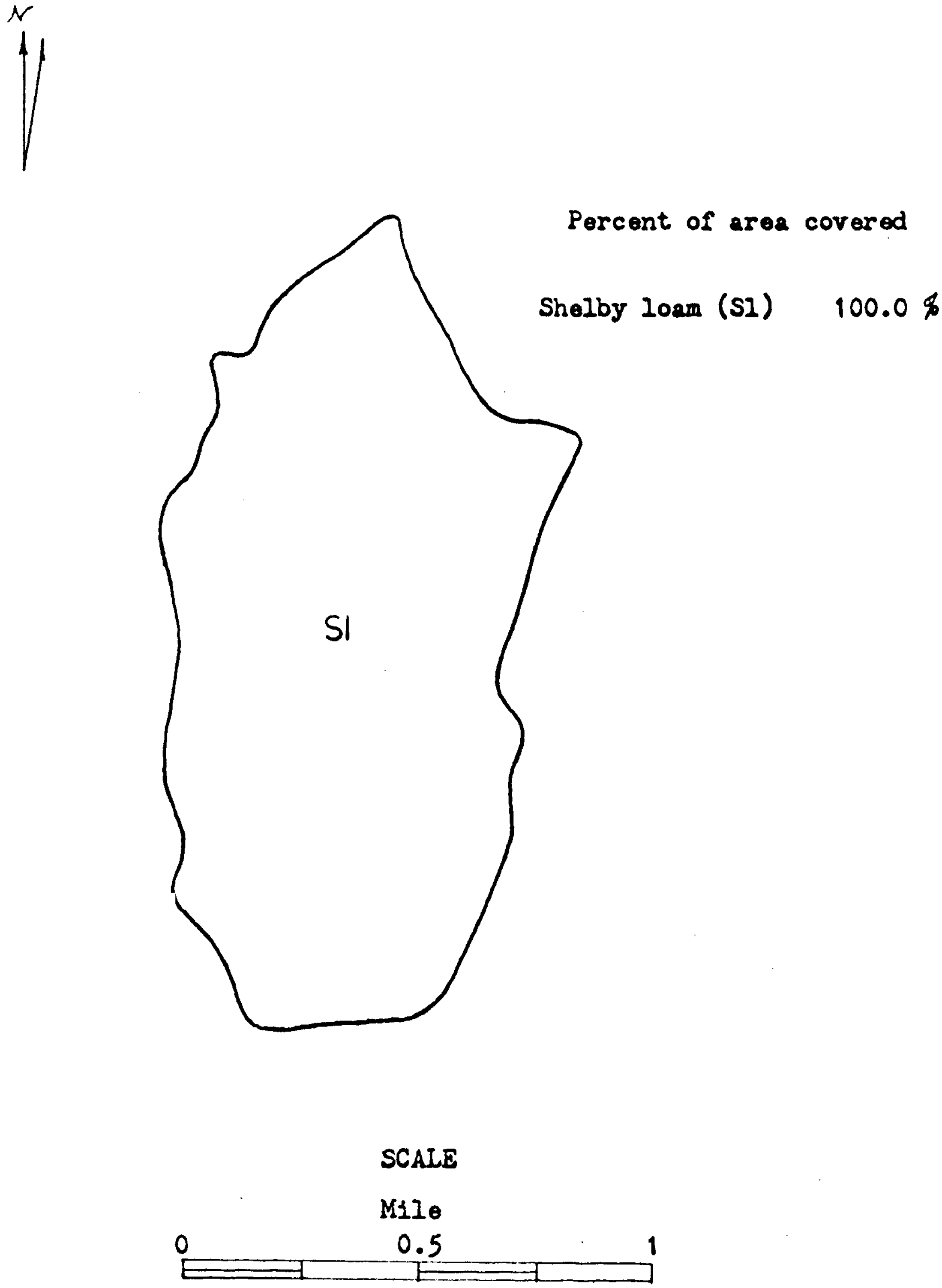


Percent of area covered

Grundy silt loam (Gl)	2.7 %
Humeston silt loam (H)	9.8 %
Lindley loam (Lm)	16.5 %
Shelby loam (Sl)	71.0 %

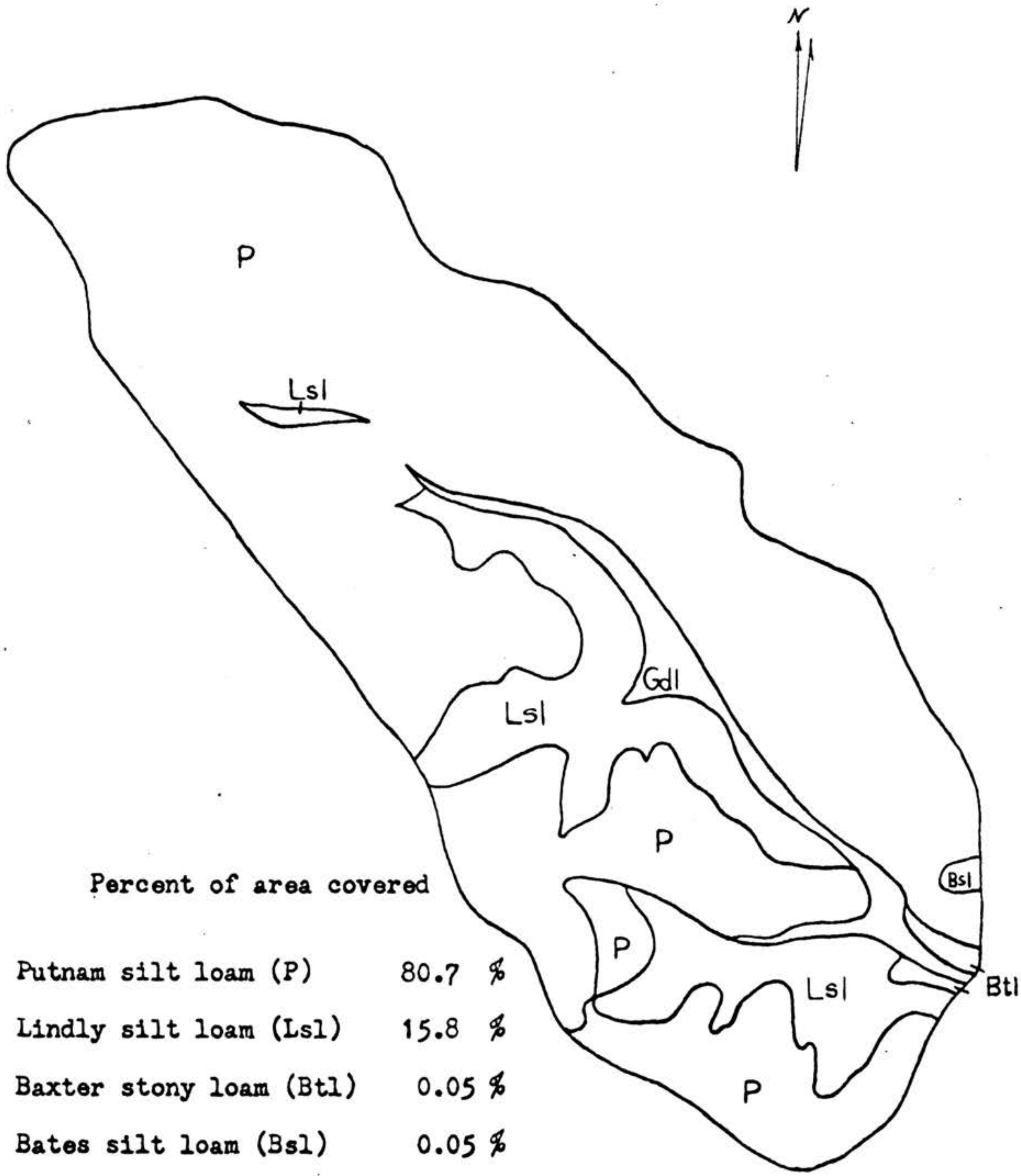
Distribution of soil types in Watershed No. 3

After Shrader, W. D., 1945



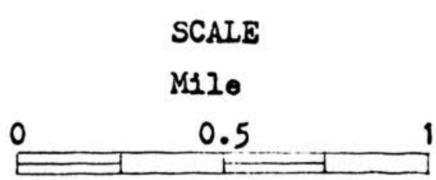
Distribution of soil type in Watershed No. 4

After Shrader, W. D., 1945



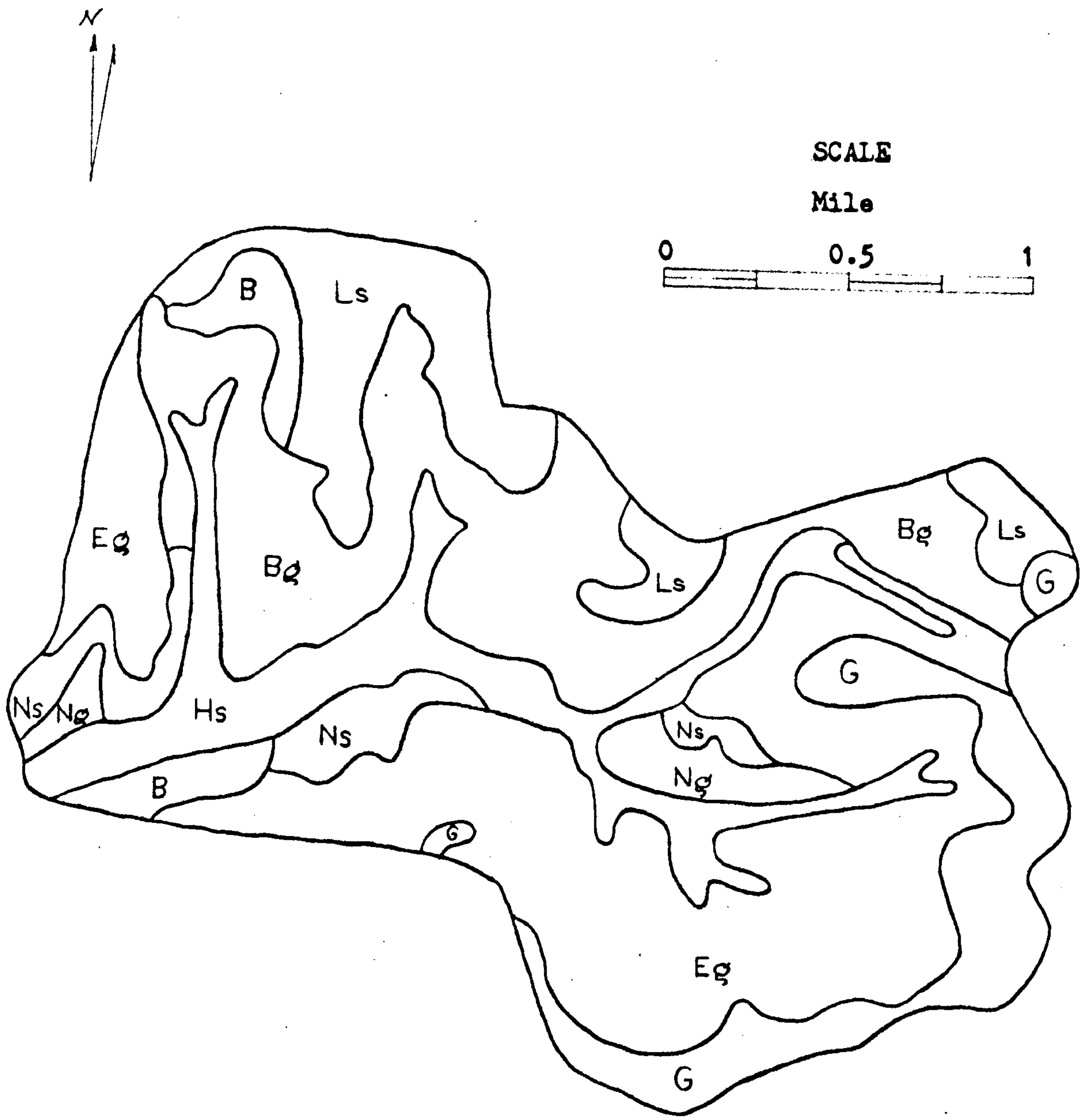
Percent of area covered

Putnam silt loam (P)	80.7 %
Lindly silt loam (Lsl)	15.8 %
Baxter stony loam (Btl)	0.05 %
Bates silt loam (Bsl)	0.05 %
Genesee sandy loam (Gdl)	3.4 %



Distribution of soil types in Watershed No. 5

After Krusekopf, H. H., 1916

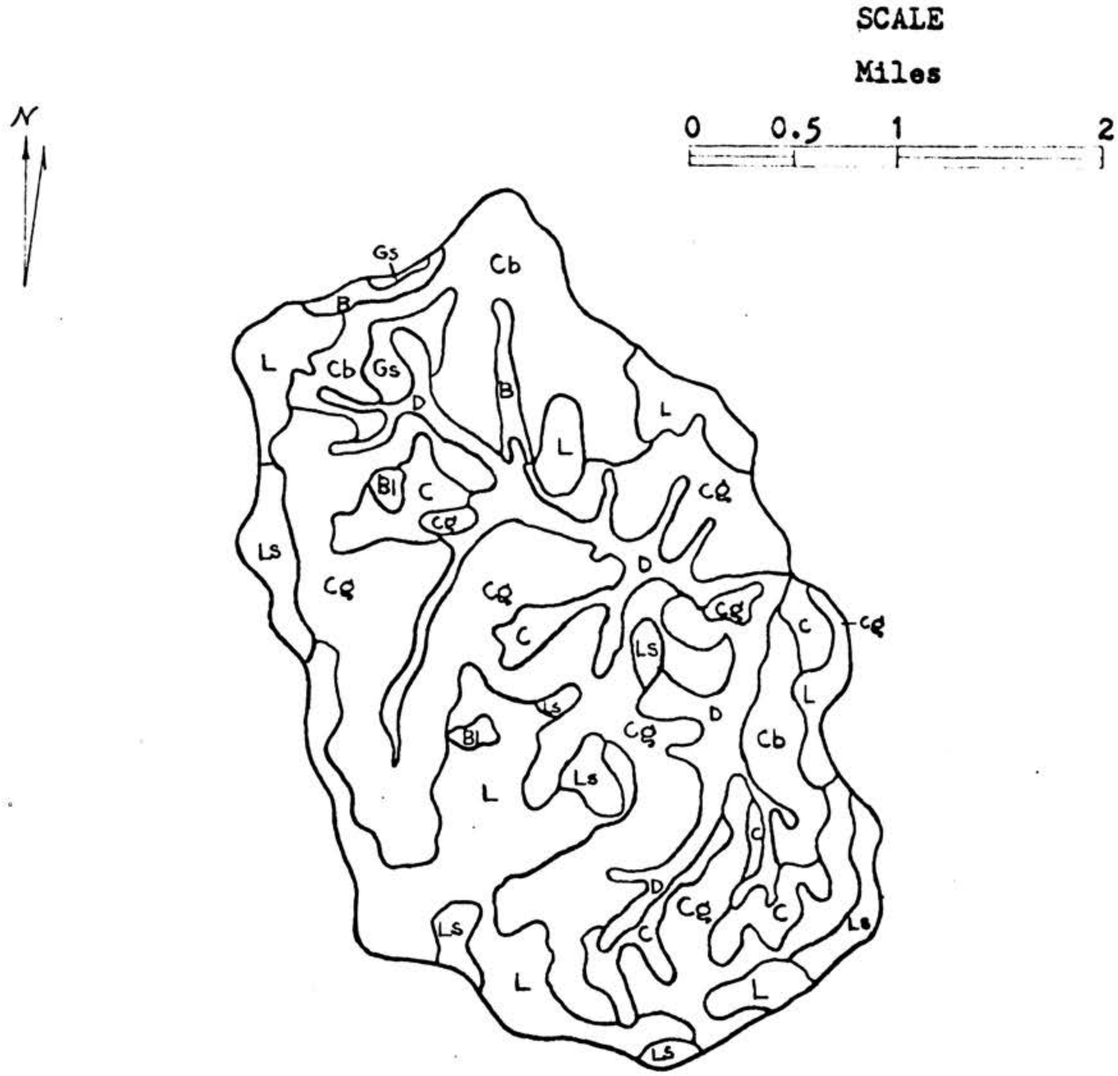


Percent of area covered

Baxter gravelly loam (B)	3.4 %
Baxter gravelly silt loam (Bg)	21.5 %
Eldon gravelly silt loam (Eg)	33.1 %
Gerald silt loam (G)	11.1 %
Huntington silt loam (Hs)	11.2 %
Lebanon silt loam (L)	10.8 %
Newtonia gravelly loam (Ng)	2.7 %
Newtonia silt loam (Ns)	6.2 %

Distribution of soil types in Watershed No. 6

After Sweet, A. T., 1923



Percent of area covered

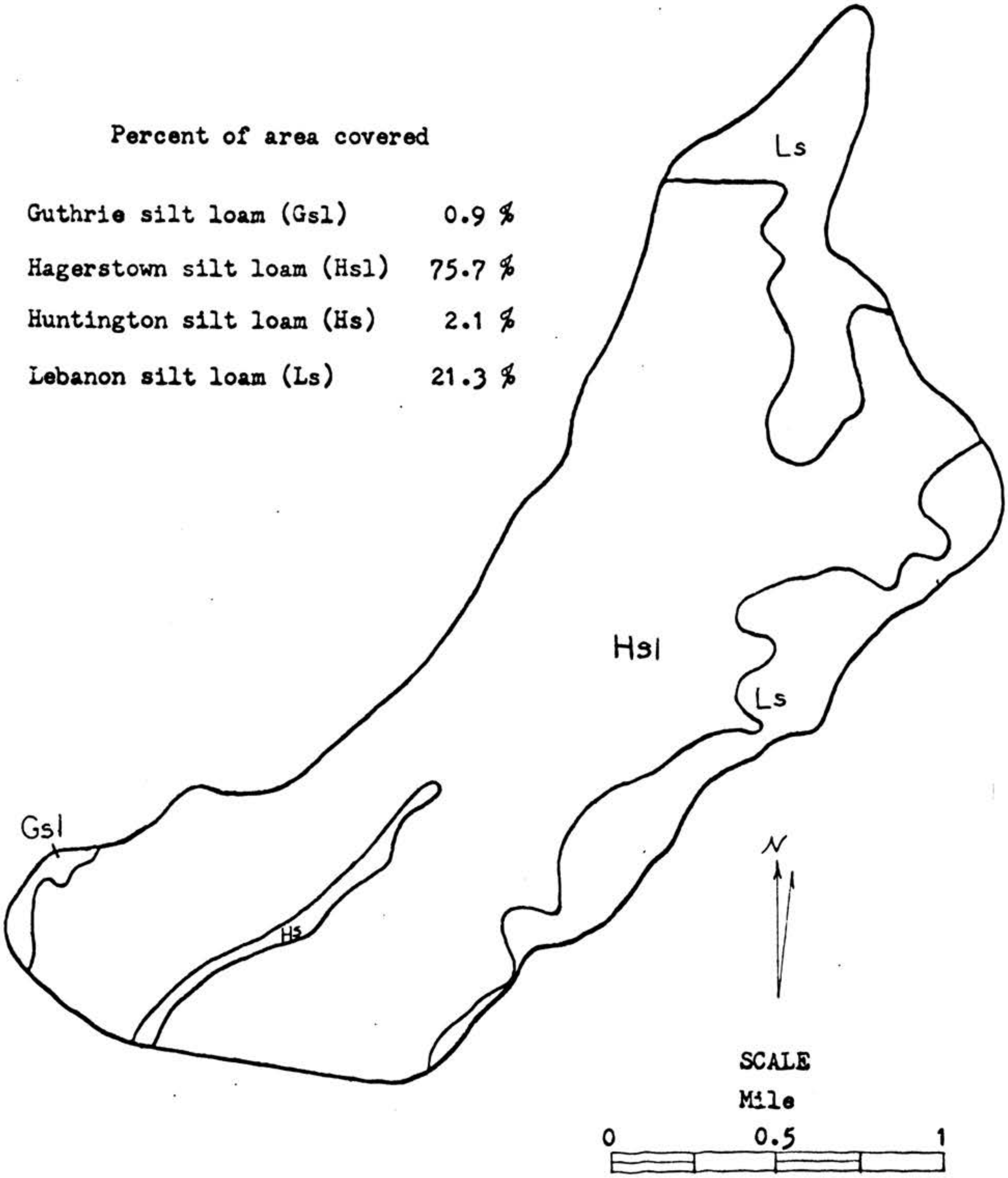
Lebanon gravelly loam (L)	20.9 %
Lebanon silt loam (Ls)	5.7 %
Clarksville stony loam (C)	9.3 %
Clarksville gravelly loam (Cg)	38.4 %
Baxter gravelly loam (B)	1.2 %
Baxter silt loam (Bl)	1.1 %
Colbert gravelly loam (Cb)	13.7 %
Gasconade stony clay (Gs)	1.2 %
Dunning gravelly loam (D)	8.5 %

Distribution of soil types in Watershed No. 7

After Watkins, W. I., 1919

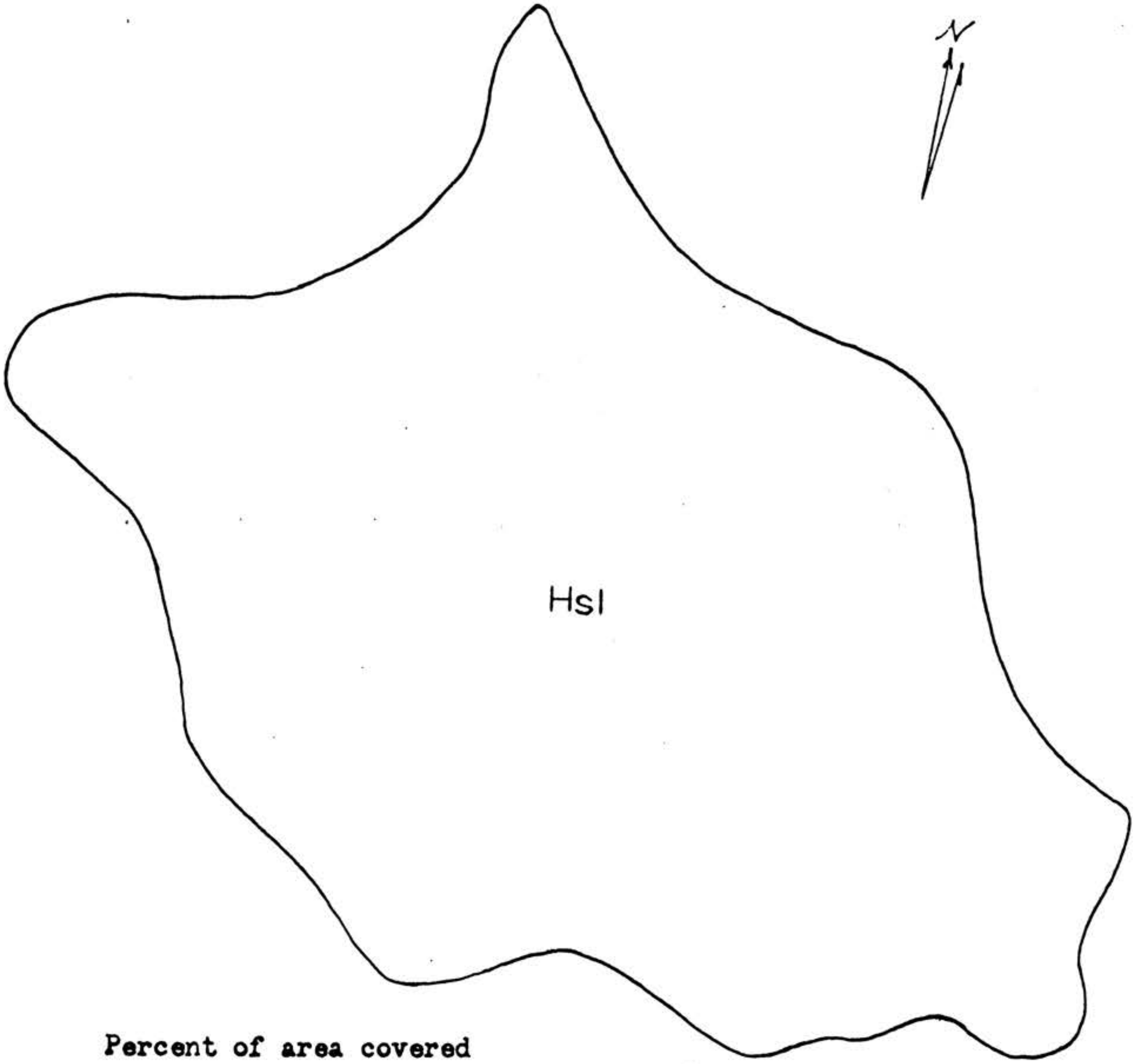
Percent of area covered

Guthrie silt loam (Gsl)	0.9 %
Hagerstown silt loam (Hsl)	75.7 %
Huntington silt loam (Hs)	2.1 %
Lebanon silt loam (Ls)	21.3 %



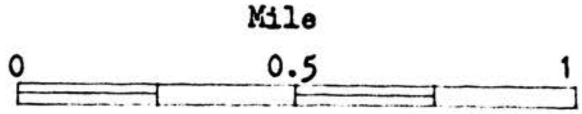
Distribution of soil types in Watershed No. 8

After Krusekopf, H. H., 1921



Percent of area covered

Hagerstown silt loam (Hsl) 100.0 %



Distribution of soil type in Watershed No. 9

After Tillman, B. W., 1913

APPENDIX IV. SOIL CHARACTERISTICS

Bates silt loam. Surface soil is dark brown to yellowish gray, mellow, light silt loam, sandstone fragments throughout; subsoil is brown, somewhat heavier silty loam, many sandstone fragments.

Baxter silt loam. 6-8 inches of brown silt loam, passing into reddish yellow silty clay loam to moderately friable and brittle clay from depths of 10-12 inches to 3 feet.

Baxter gravelly silt loam. Light brown or grayish brown to gray gravelly silt loam, overlies at depths of 15 to 18 inches a mass of angular chert fragments, 25-60 percent, of 4-5 inches diameter, with dull red or brick red, friable clay.

Baxter gravelly loam. Brown to yellow silt loam, passing into yellow or yellowish red silty clay loam at 5-6 inches deep; light red, brittle, or moderately friable clay at depth from 8-15 inches; abundant angular chert fragments on surface and subsoil.

Baxter stony loam. Differs from the Baxter gravelly loam chiefly in the larger size of the chert fragments; the typical soil is a light brown to grayish brown stony silt loam.

Carrington silt loam. Surface soil is light brownish gray or pale brown, friable silt loam; subsoil is yellowish brown silt loam, plastic when wet but breaks into hard irregularly shaped aggregates when dry; some limestone fragments are scattered throughout.

APPENDIX IV. (cont.) Soil characteristics

Clarksville gravelly loam. Brownish gray or gray silt loam; yellowish silty clay loam below 6 inches; clayey texture subsoil; about 50 percent content of angular chert gravel on surface to 3-foot section.

Clarksville stony loam. Differs from Clarksville gravelly loam chiefly in greater abundance of larger chert fragments.

Colbert gravelly loam. Gray silt loam to pale yellow silty clay loam at 4-5 inches deep, underlain at about 8 inches by yellow plastic clay; chert fragments occur from surface through subsoil.

Dunning gravelly loam. Dark gravelly loam, silty clay loam, and silty clay throughout 3-foot section, clay is rather plastic; chert fragments from surface through subsoil.

Eldon gravelly silt loam. Brown silt loam from surface to 10 or 12 feet deep, carrying chert fragments and waterworn gravel about 20 to over 70 percent of soil mass. The interstitial material of the subsoil is a lighter brown or reddish brown silt loam to silty clay loam.

Gasconade stony clay. Black clay loam to clay, underlain at 6-8 inches by yellowish, plastic, sticky, heavy clay; chert fragments occur from surface through subsoil.

Genesee sandy loam. Primarily alluvial, predominantly a dark brown to grayish brown, mellow silt loam to fine sandy loam at a depth of 2 feet or more; the soil that borders the stream has a higher content of sand.

APPENDIX IV. (cont.) Soil characteristics

Gerald silt loam. Ashy brown to dark brown silt loam, lighter brown or yellowish brown silt loam at a depth of about 8 inches; at 15-20 inches, abruptly passes into mottled, tough, and plastic silty clay loam, forming a clay pan; friable in the lower part of 3-foot section because of the higher content of silt.

Grundy silt loam. 10-14 inches of black mellow silt loam at surface; stiff, dense and plastic clay at 18 inches deep; yellowish gray, rust stained and friable clay at a depth of 28 inches.

Guthrie silt loam. Gray silt loam, passing into light gray, floury silt loam at 8-13 inches below surface, mottled faintly in places with rusty brown; passing into plastic, impervious, mottled yellow, and gray clay at 18-20 inches deep.

Hagerstown silt loam. Brown, mellow silt loam, underlain at 8-12 inches by yellow or reddish yellow, moderately friable silty clay loam; compact, reddish brown or dull red crumbly clay between 15 and 20 inches.

Humeston silt loam. Dark to gray colored alluvium, varies in color and texture according to the quantity of sand; dark gray friable silt loam at 10 to 13 inches below surface layer; dull gray friable silt loam at a depth of 20-24 inches.

Huntington silt loam. Mainly alluvial; brown, mellow silt loam throughout 3-foot section; some gravel and sand at subsoil stratum, and some chert fragments at narrower bottoms.

APPENDIX IV. (cont.) Soil characteristics

Knox silt loam. 0-8 inches, light brownish gray silt loam of fine granular structure; 8-16 inches, yellowish brown silt loam, some granular particles of 1/8 to 1/4 inch in diameter, lighter color when crushed; 16-24 inches, yellowish brown friable silty clay loam, irregularly shaped structure aggregates of 1/4 to 1/2 inch diameter, passing into some mottlings of gray and rust brown at a depth of 24-32 inches.

Lebanon silt loam. Brownish gray silt loam at surface, yellow to reddish brown clay, moderately stiff at 10-14 inches; mottled yellow and gray, somewhat friable silty clay loam or silty clay at 18-24 inches; lower subsoil is plastic and rather impervious, having the features of a clay pan.

Lebanon gravelly loam. Differs from Lebanon silt loam in being more gravelly; abundance of angular chert on surface and subsoil; hard pan of cherty layer found at depths ranging from near surface to about 24 inches.

Lindley silt loam. Surface soil is reddish brown, grayish brown to light gray silt loam, some sand present to impart a gritty feeling; subsoil is light brown to yellowish brown, granular loam, some sand, chert, and waterworn gravel throughout.

Lindley loam. Light grayish brown or yellowish gray friable loam to 4-7 inches below surface, underlain by 3-5 inches of yellow gray sandy clay; small pebbles occur in places.

APPENDIX IV. (cont.) Soil characteristics

Marshall silt loam. 0-12 inches, dark brown mellow silt loam, fine granular or crumbly structure; 12-18 inches, dark brown friable silt loam, structure particles larger and more firm than in the immediate surface layer; 18-32 inches, yellowish brown firm silty clay loam; 32-40 inches, light yellowish brown heavy silt loam.

McPaul silt loam. Mellow, brown, fine granular silt loam, varies from 10 inches to several feet thick, generally good drainage.

Newtonia silt loam. Light brown to brown silt loam, passing to reddish brown at a depth of 12-15 inches below surface; friable clay loam in upper part of the subsoil, more silty in the lower part.

Newtonia gravelly loam. Light brown to yellowish brown gravelly silt loam, grades into reddish brown to red, friable clay with a large percentage of gravel. Gravels are well rounded chert, some fragments of chert and sandstone.

Putnam silt loam. Surface soil is light gray when dry, brown to black when wet, generally containing 60-70 percent silt, pervious to water, in flatter area soil tends to be compacted; subsoil is light ashy gray to almost white silt loam, practically pure silt loam, heavier and more sticky than surface soil.

Shelby loam. Dark brown loam at surface, passing into brown loam to moderately friable clay loam at 6-8 inches deep; yellowish brown, plastic, gritty sandy clay underlies at a depth of about 14 inches. Lime concretitions and chalk occur in subsoil.

APPENDIX IV. (cont.) Soil characteristics

Wabash silt loam. 0-12 inches, dark brown or black mellow, fine granular silt loam; 12-24 inches, dark brown, coarse granular structure, friable silt loam; 24-36 inches, dark gray, fine blocky structure silt clay loam.

From: 1. Soil Survey and Map of County, 1913-1953, University of Missouri Agricultural Experiment Station
2. Geology and Soils Manual, 1962, Missouri State Highway Commission

APPENDIX V. APPROXIMATE TEXTURAL COMPOSITION OF SOME MISSOURI SOIL TYPES

Soil type	Gravel	Sand	Silt	Clay
Gravelly loam	35 %	25 %	25 %	15 %
Gravelly silt loam	25	25	40	10
Stony loam	45	25	20	10
Stony clay	15	15	25	45
Sand	-	87	7	6
Sandy loam	-	65	25	10
Sandy clay loam	-	62	13	25
Sandy clay	-	55	10	35
Silt	-	7	88	5
Silty loam	-	25	65	10
Silty clay loam	-	12	63	25
Silty clay	-	7	58	35
Clay	-	25	25	50
Clay loam	-	38	38	24
Loam	-	45	45	10

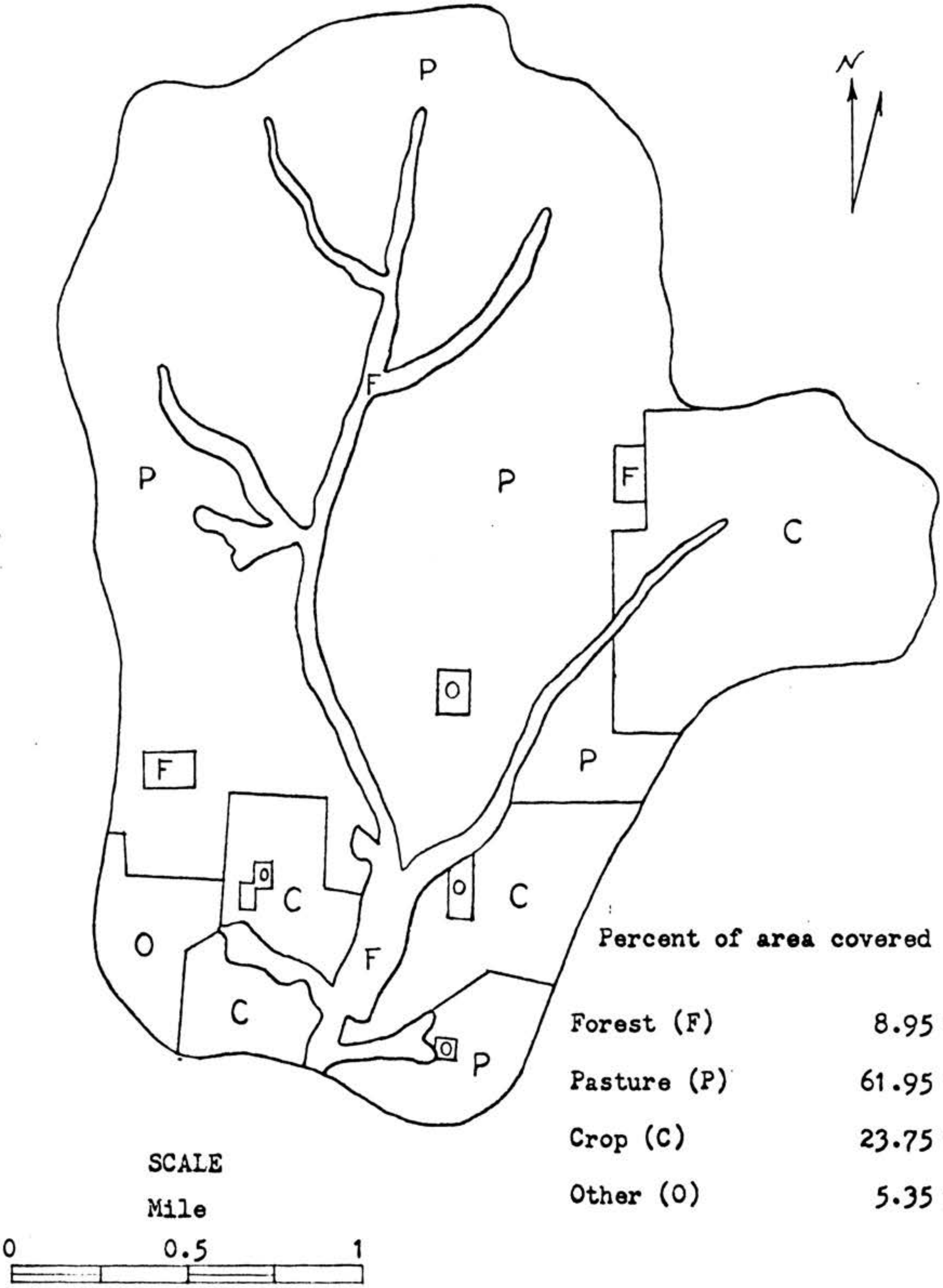
From Geology and Soils Manual, 1962, Missouri State Highway Commission

APPENDIX VI

MAPS SHOWING DISTRIBUTION AND PERCENTAGE OF WATERSHED AREAS COVERED

BY

VEGETAL CATEGORIES

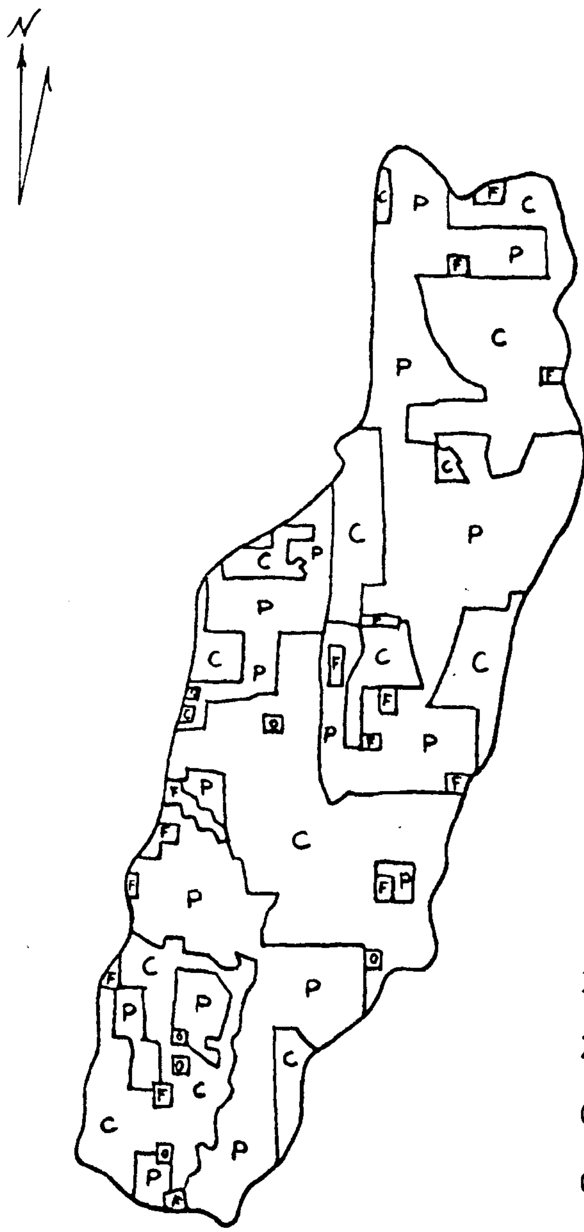


Percent of area covered

Forest (F)	8.95 %
Pasture (P)	61.95 %
Crop (C)	23.75 %
Other (O)	5.35 %

Distribution of vegetal categories in Watershed No. 1

From U.S.D.A. Aerial Photograph, 1960



Percent of area covered

Forest (F)	1.97 %
Pasture (P)	55.02 %
Crop (C)	41.46 %
Other (O)	1.55 %

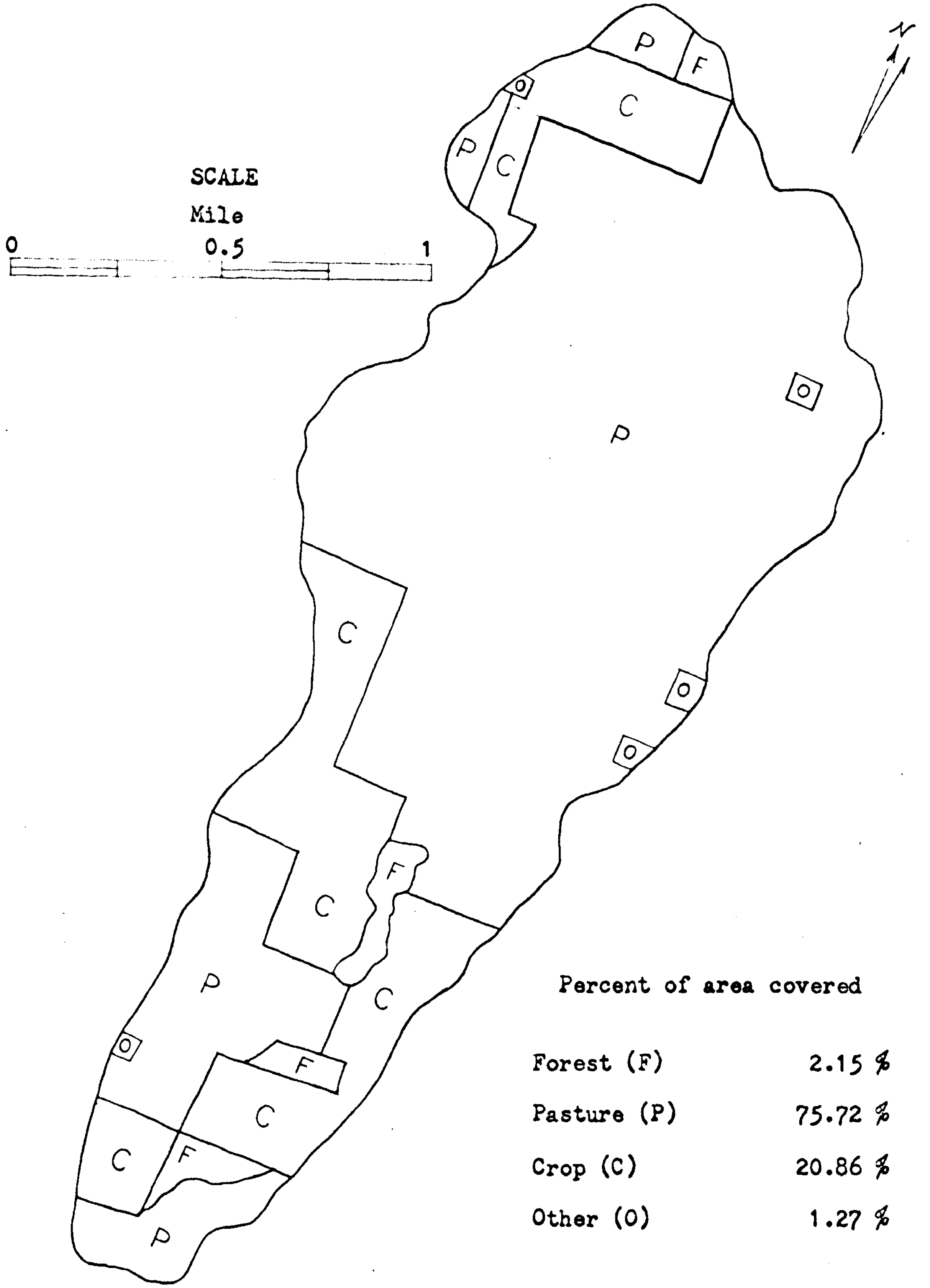
SCALE

Miles

0 0.5 1 2 3

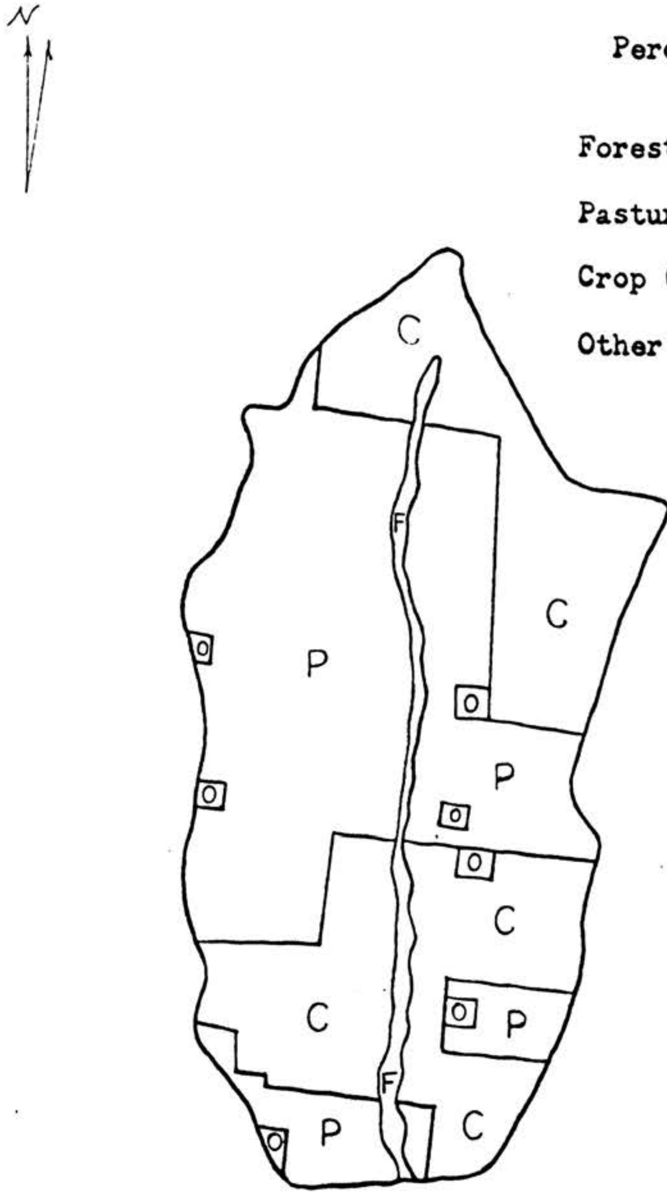
Distribution of vegetal categories in Watershed No. 2

From U.S.D.A. Aerial Photograph, 1960



Distribution of vegetal categories in Watershed No. 3

From U.S.D.A. Aerial Photograph, 1963

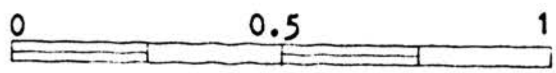


Percent of area covered

Forest (F)	4.04 %
Pasture (P)	51.06 %
Crop (C)	40.77 %
Other (O)	4.13 %

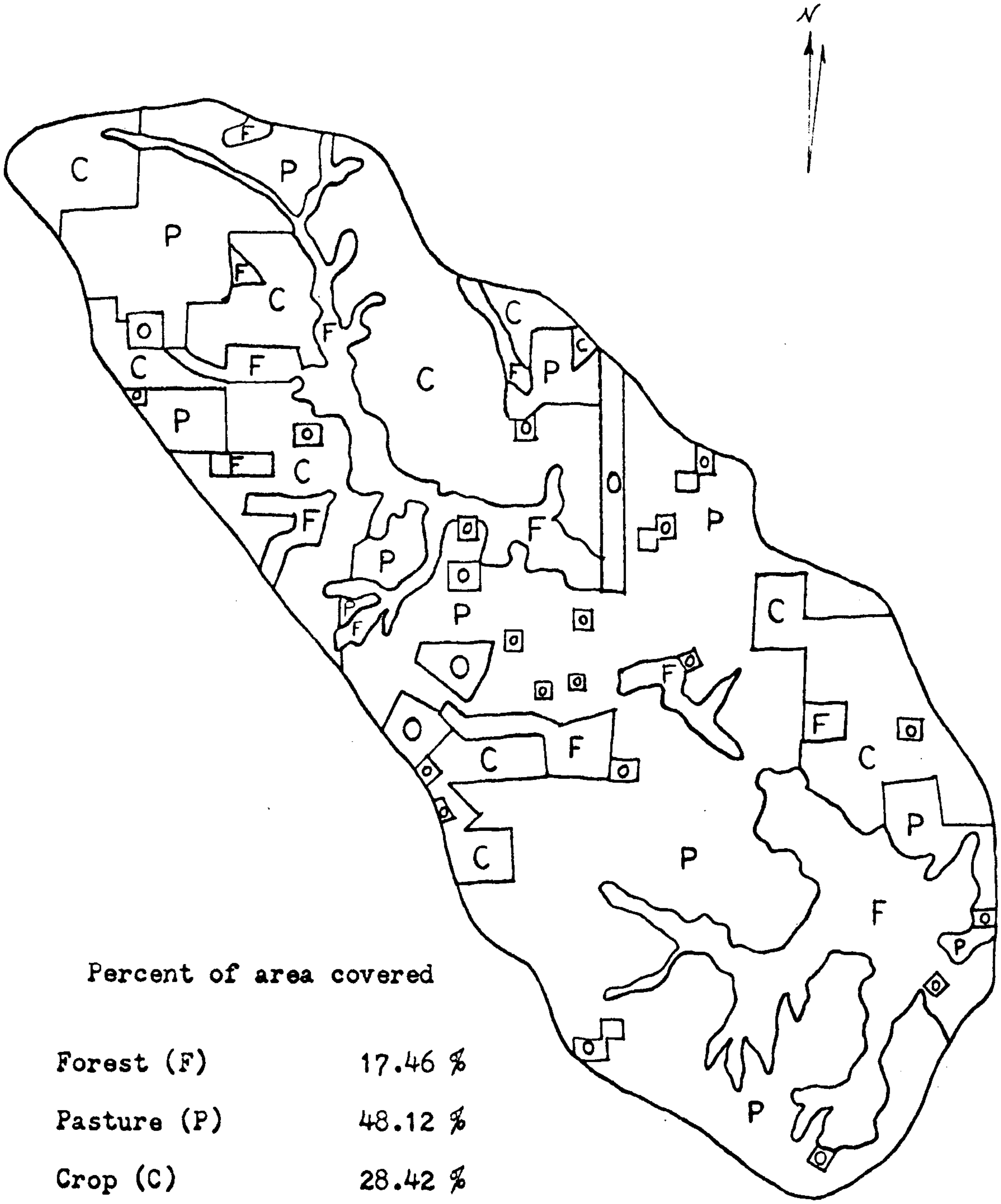
SCALE

Mile



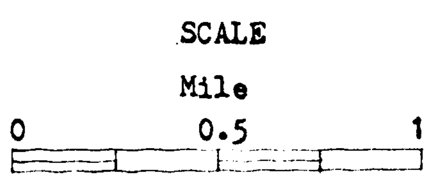
Distribution of vegetal categories in Watershed No. 4

From U.S.D.A. Aerial Photograph, 1963



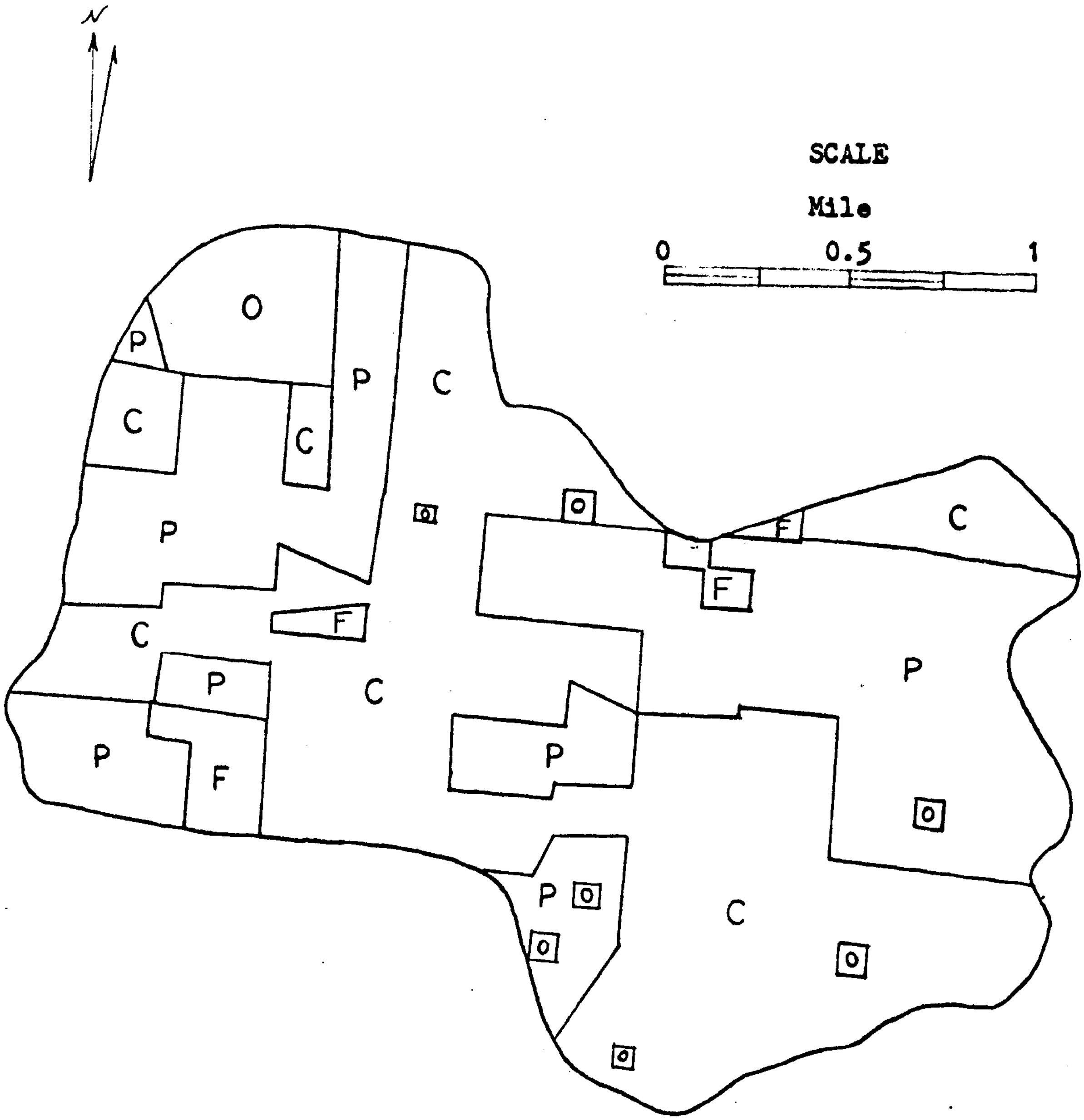
Percent of area covered

Forest (F)	17.46 %
Pasture (P)	48.12 %
Crop (C)	28.42 %
Other (O)	6.0 %



Distribution of vegetal categories in Watershed No. 5

From U.S.D.A. Aerial Photograph, 1962

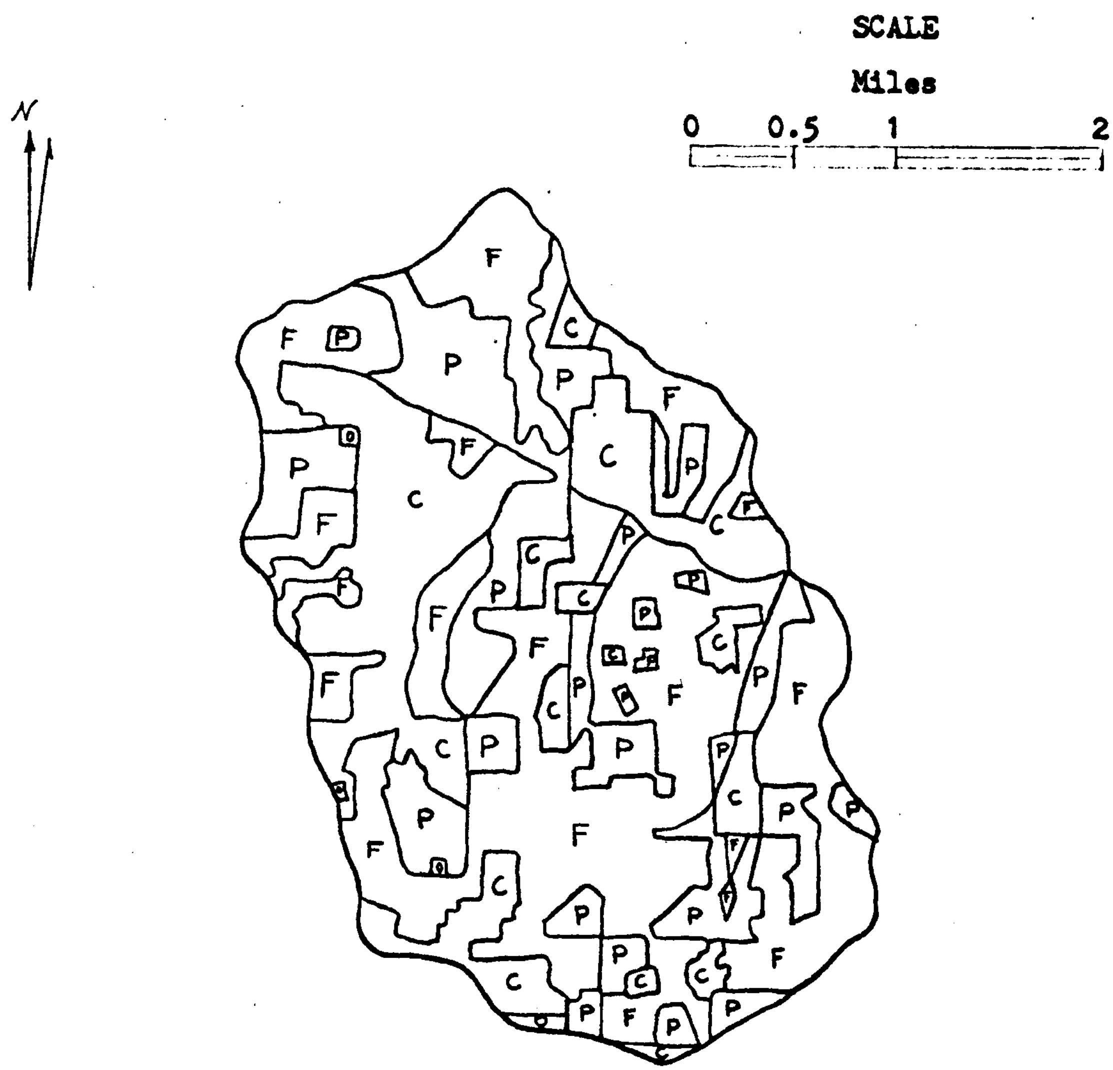


Percent of area covered

Forest (F)	4.48 %
Pasture (P)	37.65 %
Crop (C)	45.13 %
Other (O)	12.74 %

Distribution of vegetal categories in Watershed No. 6

From U.S.D.A. Aerial Photograph, 1960



Percent of area covered

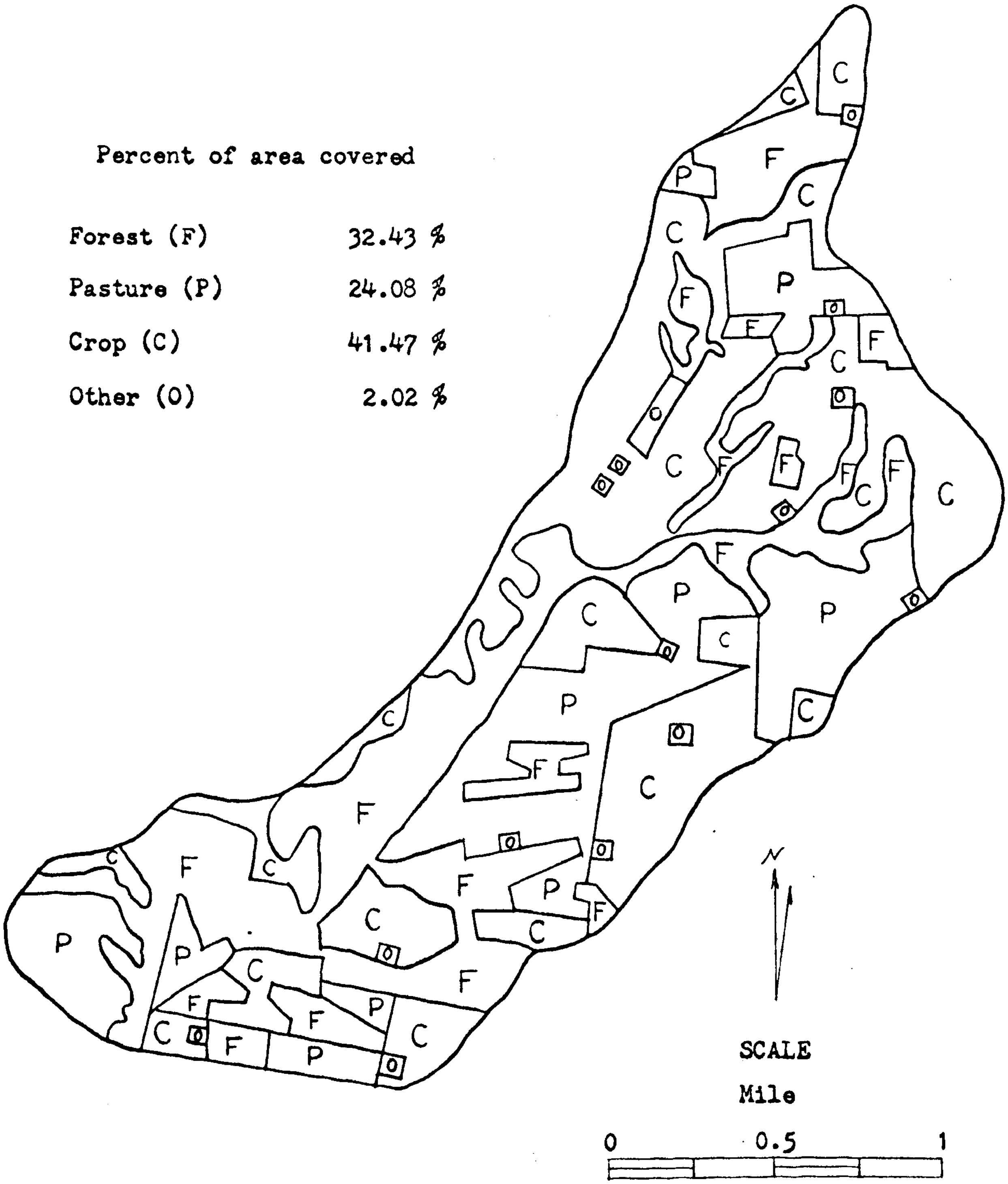
Forest (F)	49.10 %
Pasture (P)	24.48 %
Crop (C)	25.39 %
Other (O)	1.03 %

Distribution of vegetal categories in Watershed No. 7

From U.S.D.A. Aerial Photograph, 1959

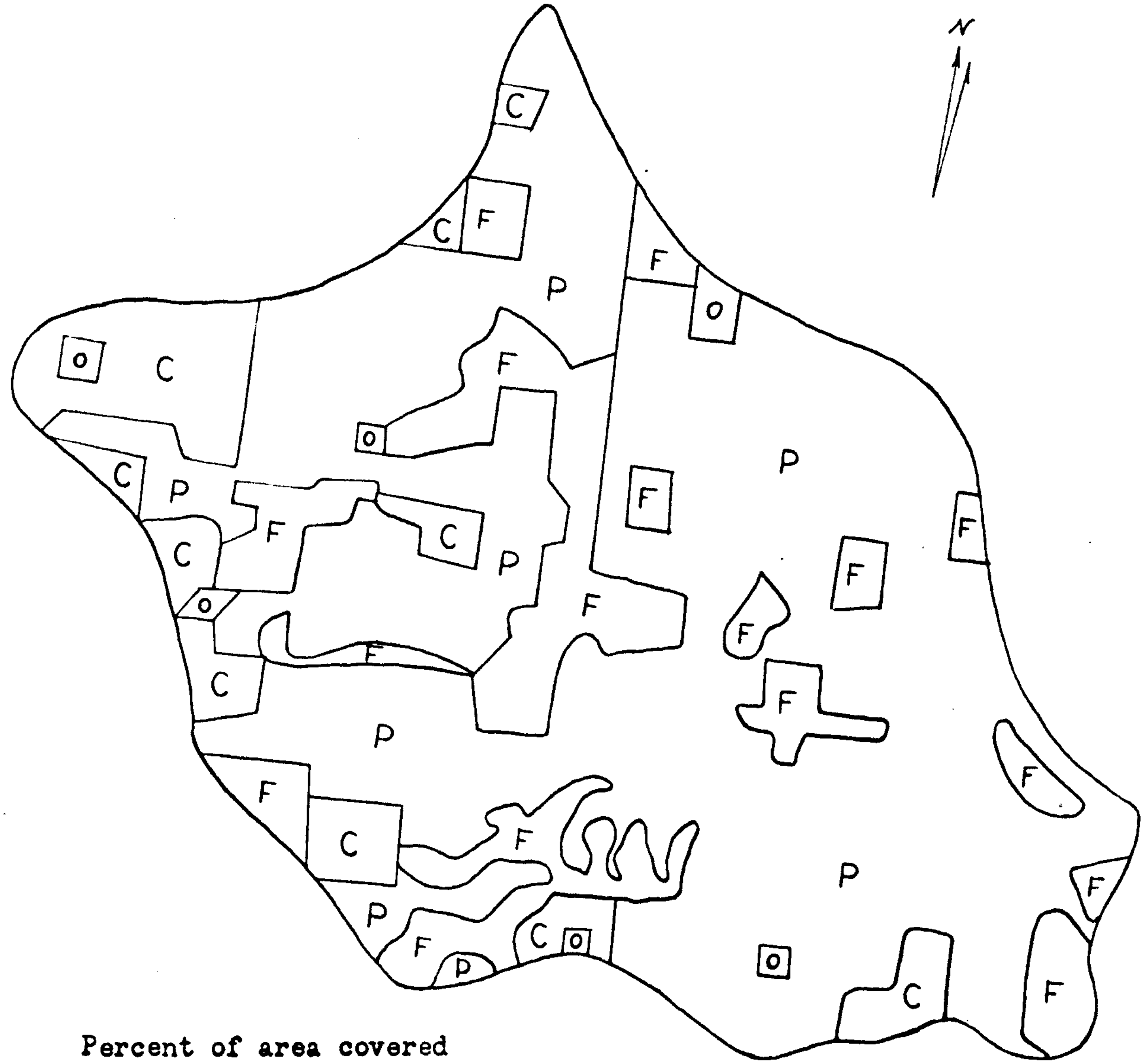
Percent of area covered

Forest (F)	32.43 %
Pasture (P)	24.08 %
Crop (C)	41.47 %
Other (O)	2.02 %



Distribution of vegetal categories in Watershed No. 8

From U.S.D.A. Aerial Photograph, 1959



Percent of area covered

Forest (F)	8.95 %
Pasture (P)	61.95 %
Crop (C)	23.75 %
Other (O)	5.35 %

SCALE

Mile

0 0.5 1

Distribution of vegetal categories in Watershed No. 9

From U.S.D.A. Aerial Photograph, 1959

APPENDIX VII. LITHOLOGIC CHARACTERISTICS OF BEDROCK FORMATIONS

Severy shale (Pennsylvanian). Gray to black, argillaceous, fossiliferous; locally contains black concretionary limestone.

Calhoun shale (Pennsylvanian). Brown to black, fossiliferous, slaty and sandy, some thin coal seam.

Howard limestone (Pennsylvanian). Deep blue, compact, fossiliferous, thin shale interbedded.

Fort Scott limestone (Pennsylvanian). Light gray, thin bedded, cherty, highly fossiliferous.

Marmaton limestone (Pennsylvanian). Dark blue, massive, some shale and coal interbedded.

Burlington limestone (Mississippian). Bluish gray, medium-grained, cherty, crinoidal at lower part.

Plattin limestone (Ordovician). Bluish gray, massive, evenly bedded, nondolomitic, some chert nodules; cave system and sinkholes occurred in Perry County.

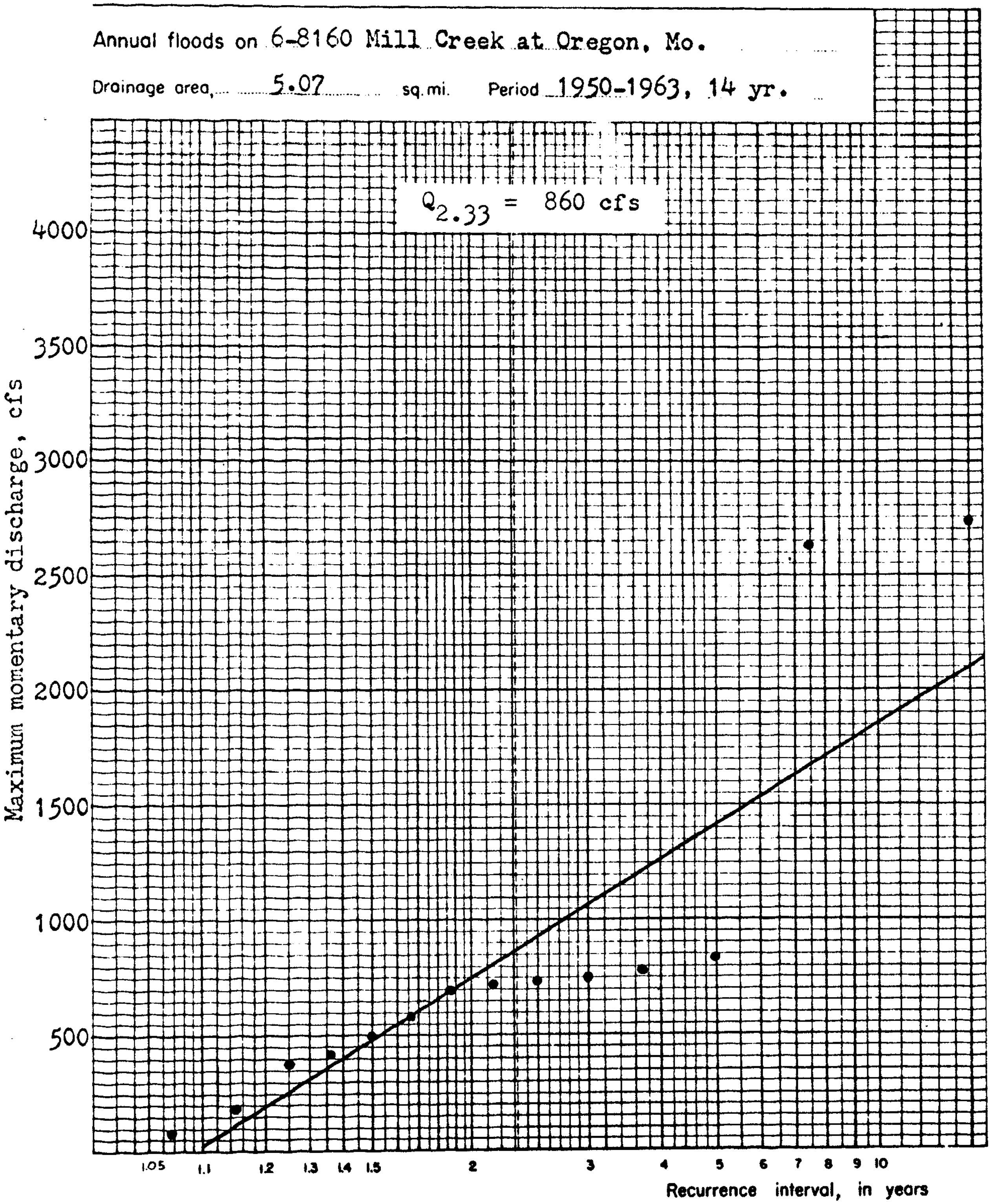
Cotter dolomite (Ordovician). White to brownish gray, massive, argillaceous, thin bedded.

Jefferson City dolomite (Ordovician). White, gray, yellow, or buff, fine-grained, cherty, medium to massive, sandstone interbedded.

Bonneterre dolomite (Cambrian). Light gray, massive bedding, some sandy and calcareous sandstone interbedded, glauconitic at lower part.

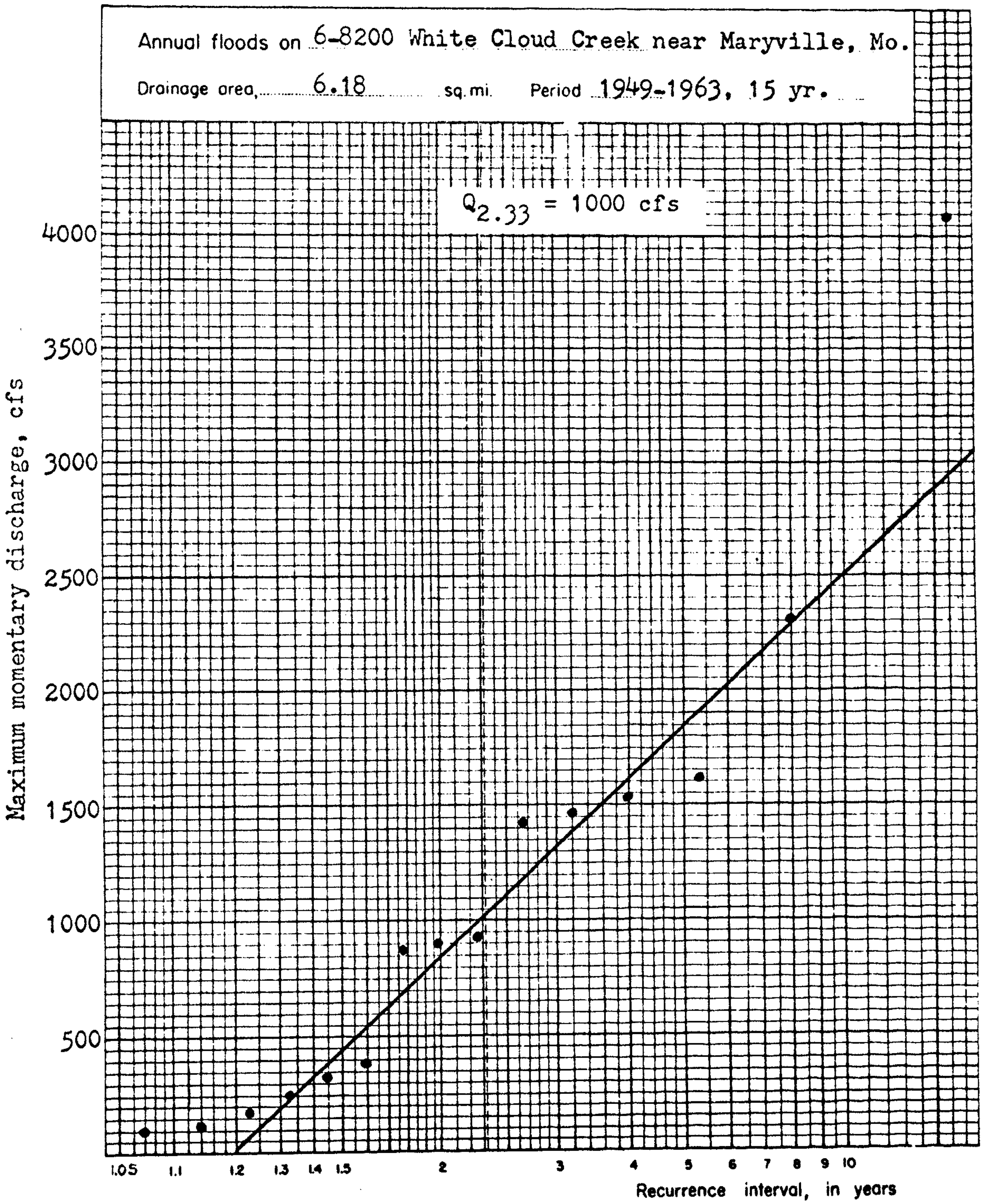
From various sources; see text

APPENDIX VIII. FLOOD FREQUENCY CURVES FOR WATERSHEDS



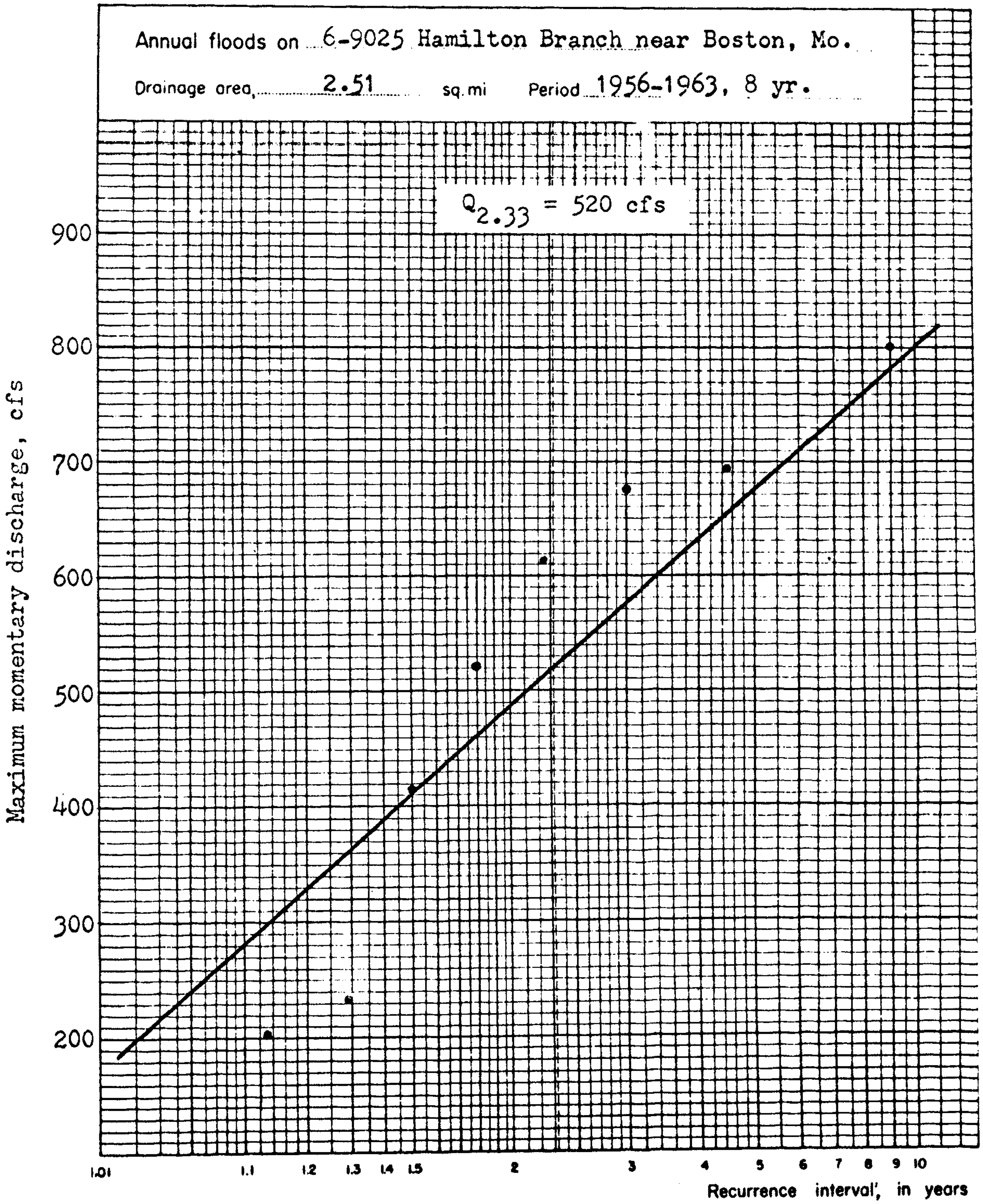
Frequency curve for Watershed No. 1

APPENDIX VIII. (cont.) Frequency curves



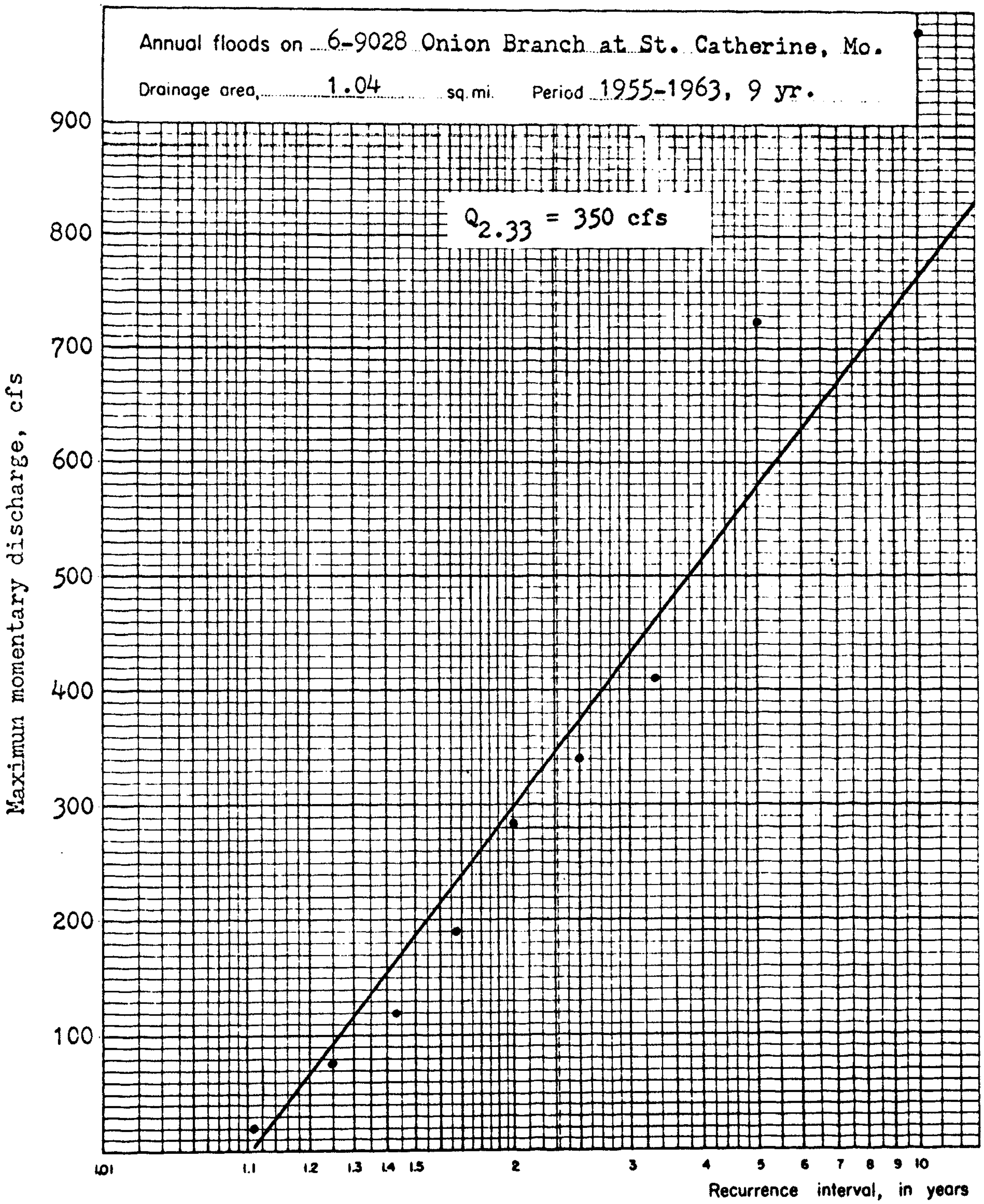
Frequency curve for Watershed No. 2

APPENDIX VIII. (cont.) Frequency curves



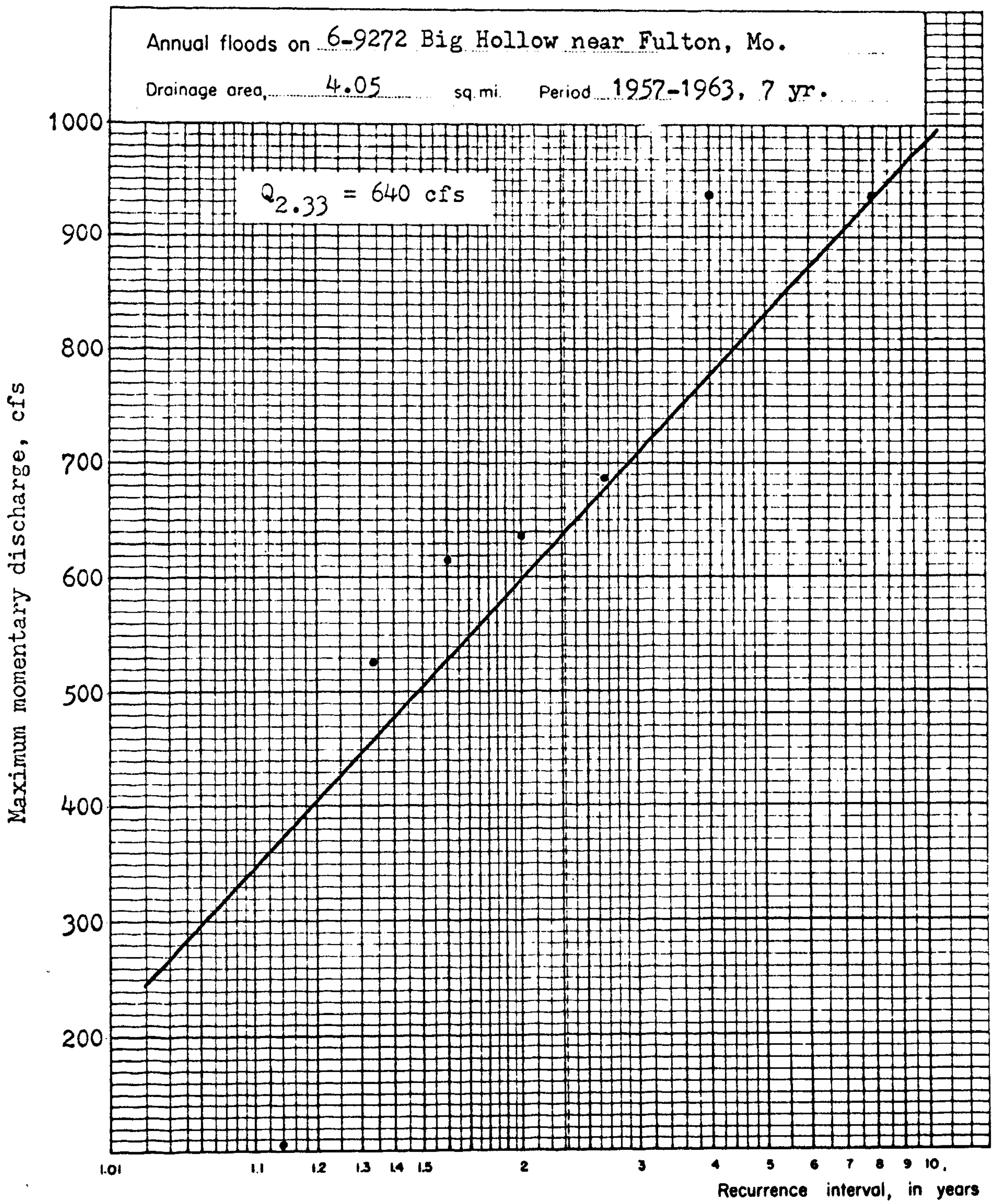
Frequency curve for Watershed No. 3

APPENDIX VIII. (cont.) Frequency curves



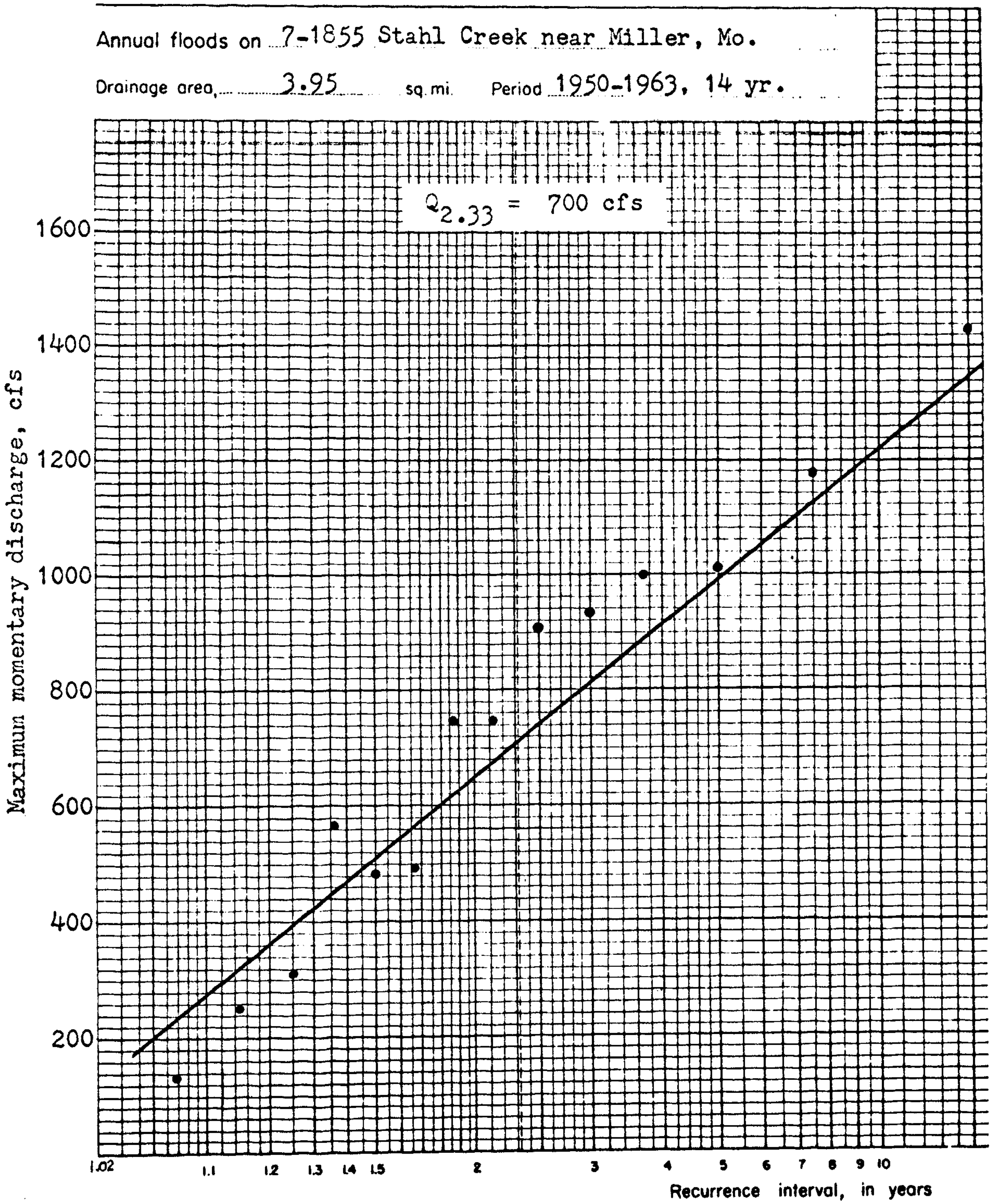
Frequency curve for Watershed No. 4

APPENDIX VIII. (cont.) Frequency curves



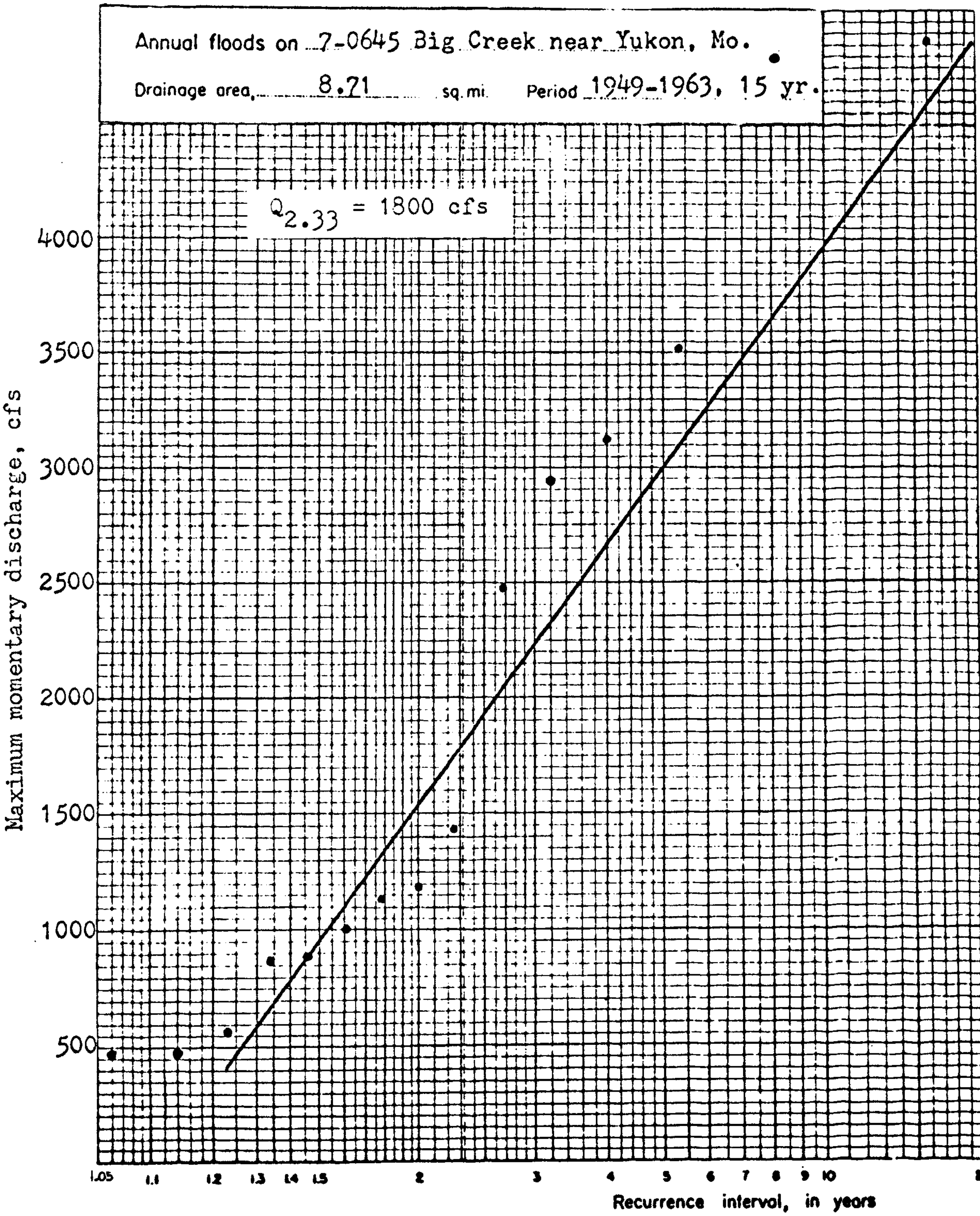
Frequency curve for Watershed No. 5

APPENDIX VIII. (cont.) Frequency curves



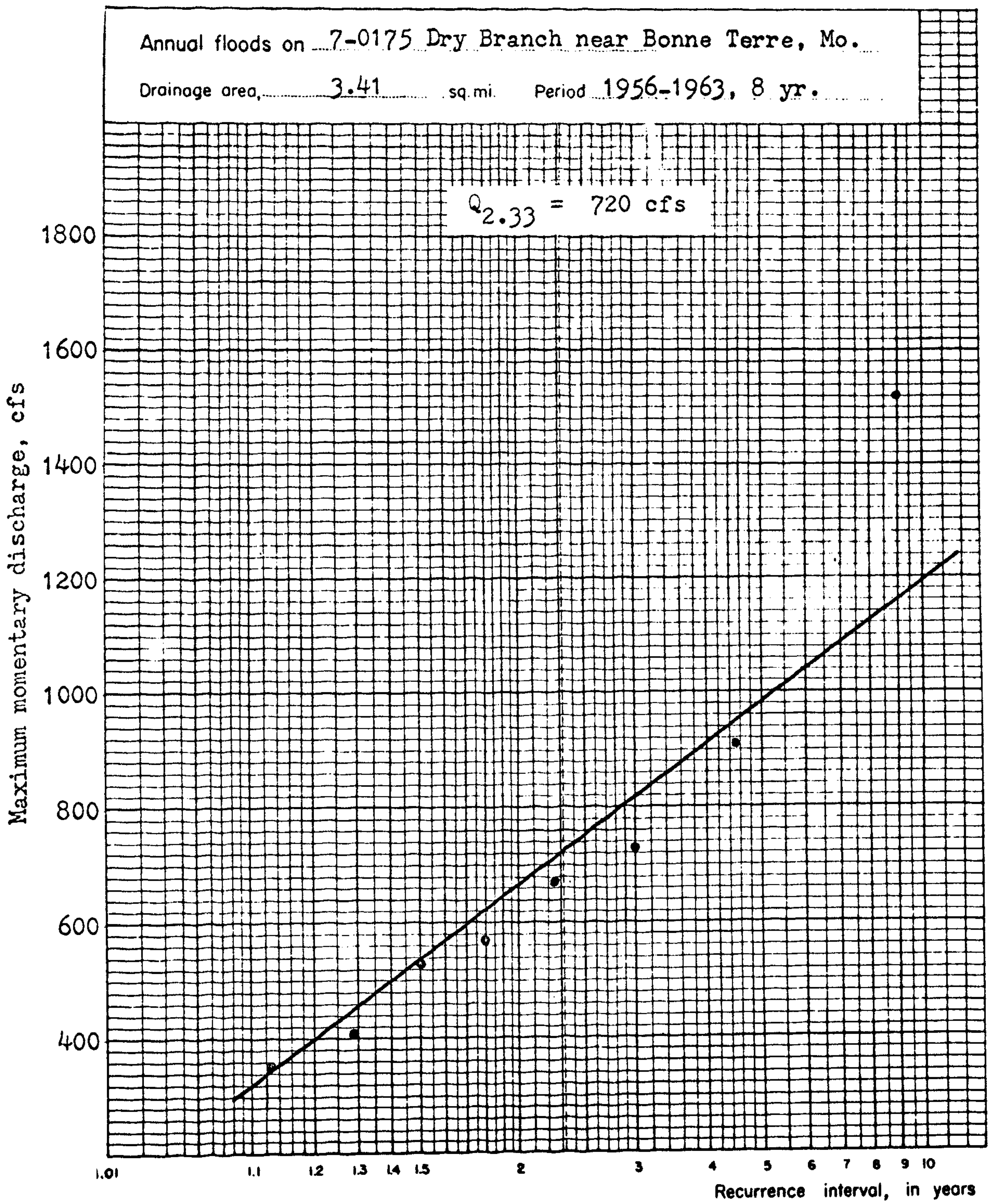
Frequency curve for Watershed No. 6

APPENDIX VIII. (cont.) Frequency curves



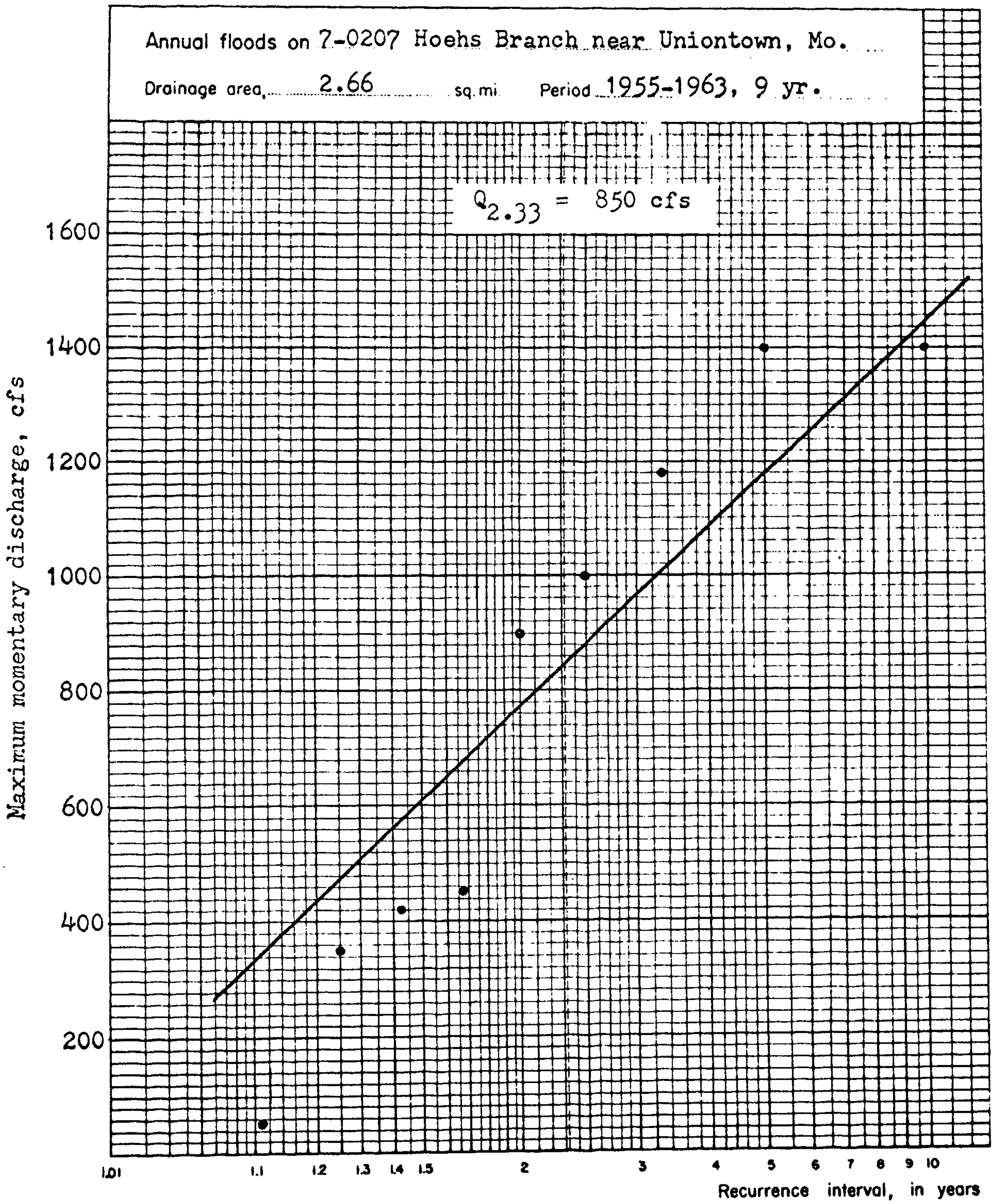
Frequency curve for Watershed No. 7

APPENDIX VIII. (cont.) Frequency curves



Frequency curve for Watershed No. 8

APPENDIX VIII. (cont.) Frequency curves



Frequency curve for Watershed No. 9

APPENDIX IX. WATERSHED FACTORS, BASIN INDEX, ESTIMATED AND MEASURED MEAN ANNUAL FLOOD

Watershed	Area, sq. mile		Length, mile		Slope, ft/ft	
Number	Narupon	Harbaugh	Narupon	Harbaugh	Narupon	Harbaugh
1	5.07	4.90	3.37	3.3	0.012	0.011
2	6.18	6.06	5.74	5.8	0.004	0.004
3	2.51	2.51	4.03	4.1	0.008	0.007
4	1.04	1.04	1.84	1.8	0.012	0.012
5	4.05	4.05	3.92	4.0	0.008	0.008
6	3.95	3.87	2.78	3.0	0.014	0.010
7	8.71	8.36	4.05	4.1	0.013	0.012
8	3.41	3.65	4.47	4.1	0.014	0.014
9	2.66	1.66	2.25	2.2	0.010	0.012

Watershed	Basin Index		Estimated MAF	Measured MAF	Difference MAF
Number	Narupon	Harbaugh	cfs/sq. mi.	cfs/sq. mi.	cfs/sq. mi.
1	5.80	5.62	129.60	169.63	- 40.03
2	13.20	12.90	240.54	165.02	+ 75.52
3	3.53	3.53	158.92	207.17	- 48.25
4	1.93	1.93	389.71	336.54	+ 53.17
5	5.50	5.82	153.70	158.02	- 4.32
6	3.65	3.48	104.42	177.22	- 72.80
7	14.60	15.50	189.41	206.66	- 17.25
8	8.33	7.23	276.04	211.14	+ 64.90
9	1.35	4.63	57.35	319.55	-262.20

VITA

Anant Suthipas Narupon was born on April 17, 1927, in Thailand. After primary and secondary school, he entered Chulalongkorn University, Bangkok, Thailand, where he received B. S. degree in Mining Engineering in 1953.

Since graduation, to the present time, he has been employed by the Royal Irrigation Department of Thailand. From 1953 to 1962, he worked as a resident geologist for the construction of Chao Phya and Bhumibol Dam Projects, Thailand.

During 1958, he was sent to the United States by the Royal Irrigation Department of Thailand for a six months program of tunnel operation training at Glen Canyon Dam, Arizona.

In 1962, the Royal Irrigation Department sent him for the second time to the United States for a one year program of engineering training at the U. S. Bureau of Reclamation, Denver, Colorado.

After this training program, he received the Thai Government Scholarship for further studies at the University of Missouri at Rolla, beginning with the fall semester, 1963, as a candidate for the Degree of Master of Science in Geological Engineering.